Predicted Impacts from Offshore Produced Water Discharges on Hypoxia in the Gulf of Mexico

Presented by

Scott Wilson

U.S. Environmental Protection Agency, Region 6

Study Prepared by:

Victor J. Bierman, Jr.

Limno-Tech, Inc.

For

U.S. Environmental Protection Agency, Region 6

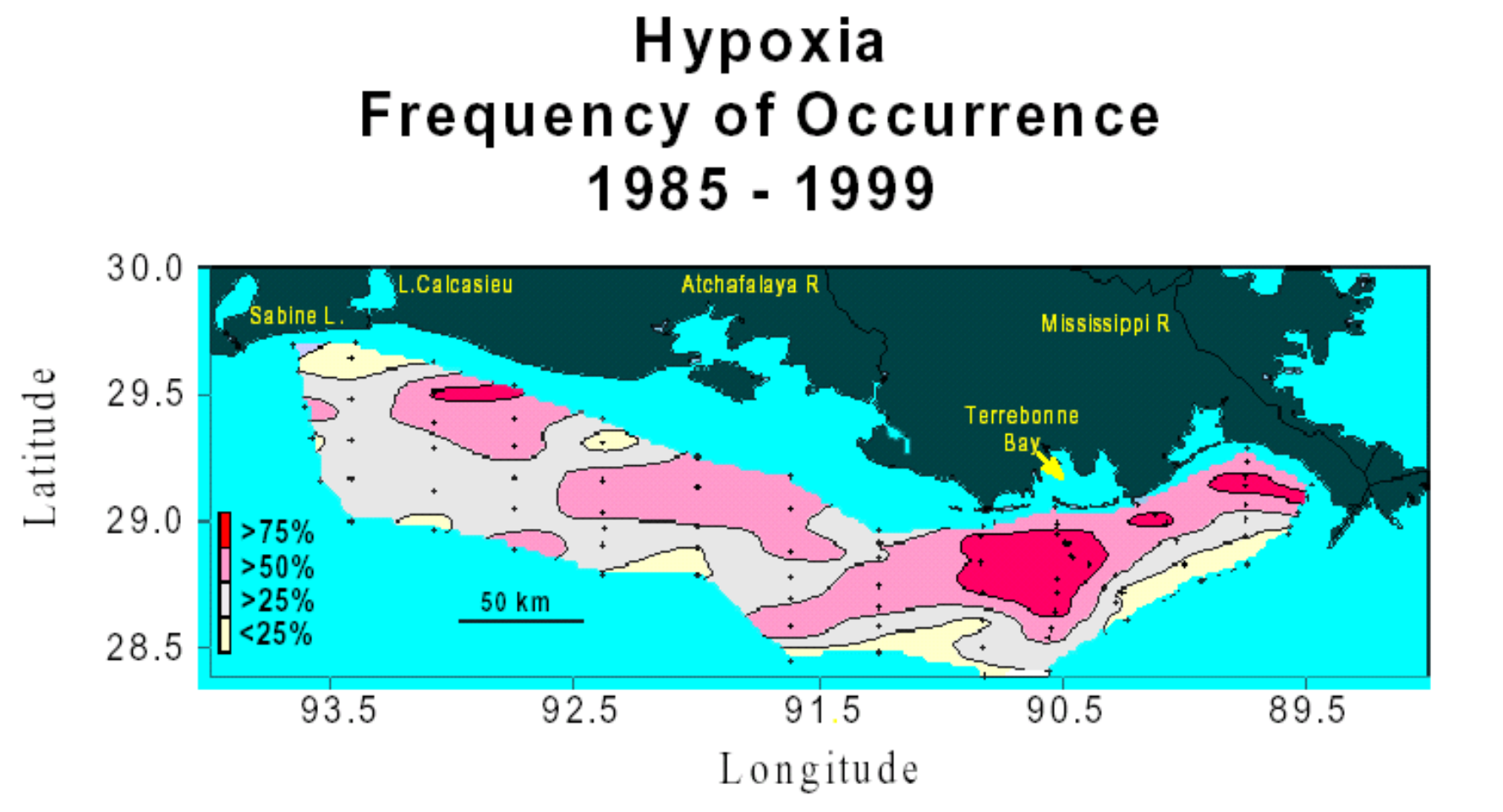
Presentation Outline

- Study objectives
- Background on hypoxia
- Study approach
- Contributions of produced water loads
- Models of Gulf hypoxia
- Design of predictive scenarios
- Results
- Conclusions

Study Objectives

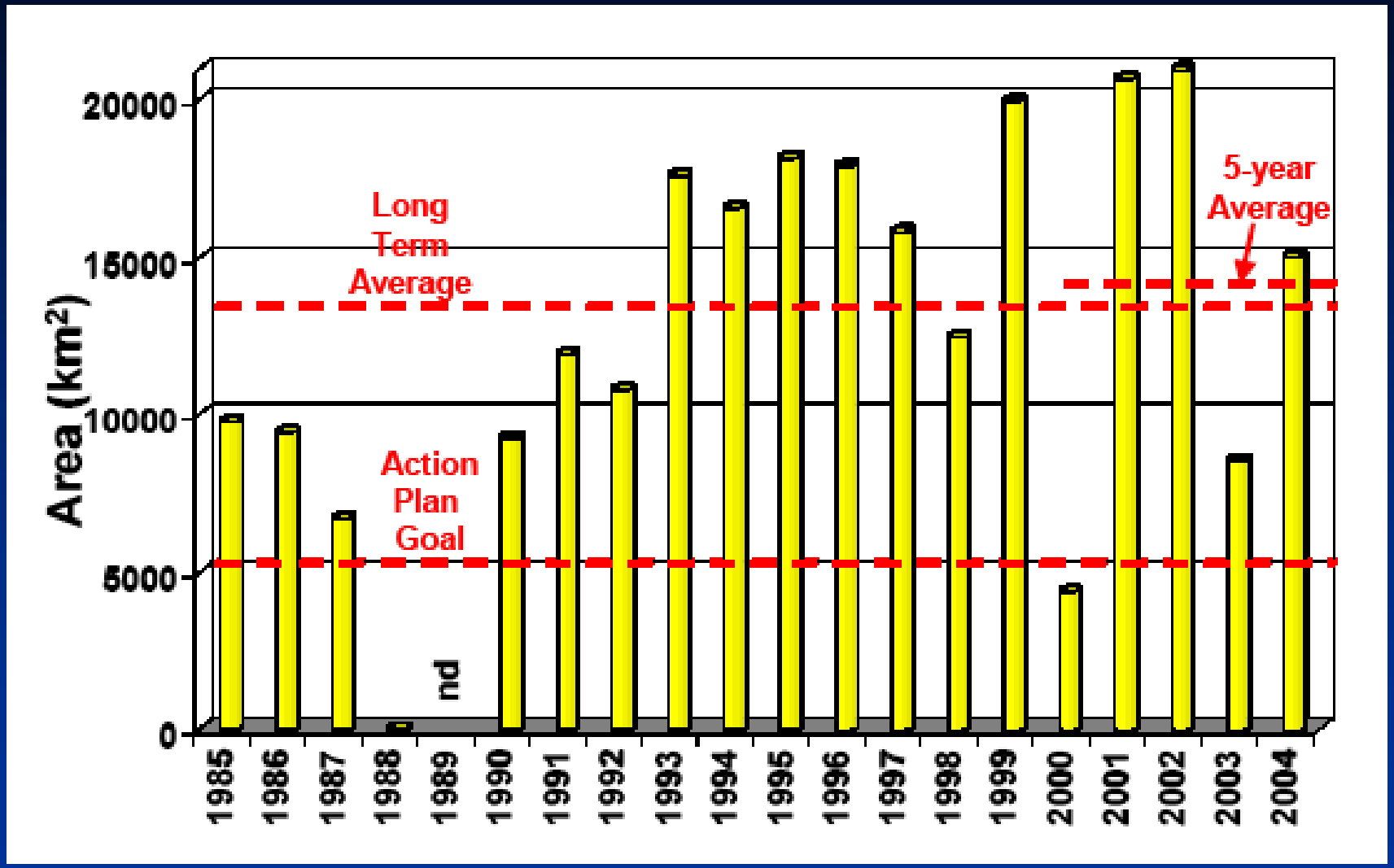
- Assess incremental impacts of produced water discharges on dissolved oxygen in the northern Gulf of Mexico.
- Evaluate the significance of these discharges relative to loadings from the Mississippi River Basin (MRB).

Areal Extent of Gulf Hypoxia



Data from Rabalais et al. 2002

Interannual Trend

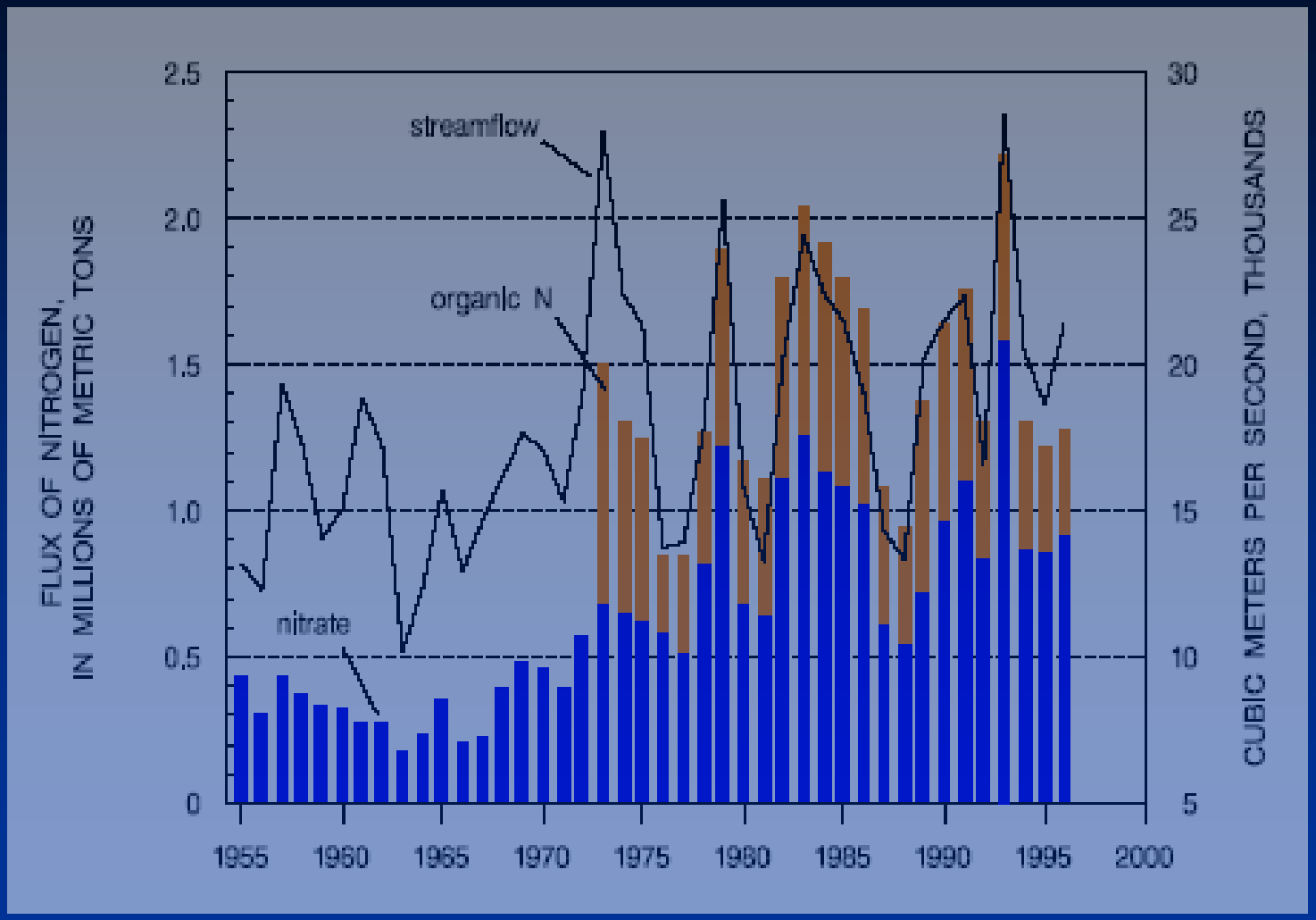


Data from Rabalais et al. 2002

Causes of Hypoxia

- Anthropogenic
  - Excessive nutrient loadings (primarily nitrogen) from the MRB
- Natural
  - Physical stratification of Gulf waters
    - Precipitation
    - Temperature
    - Weather patterns

MRB Nitrogen Load and Flow

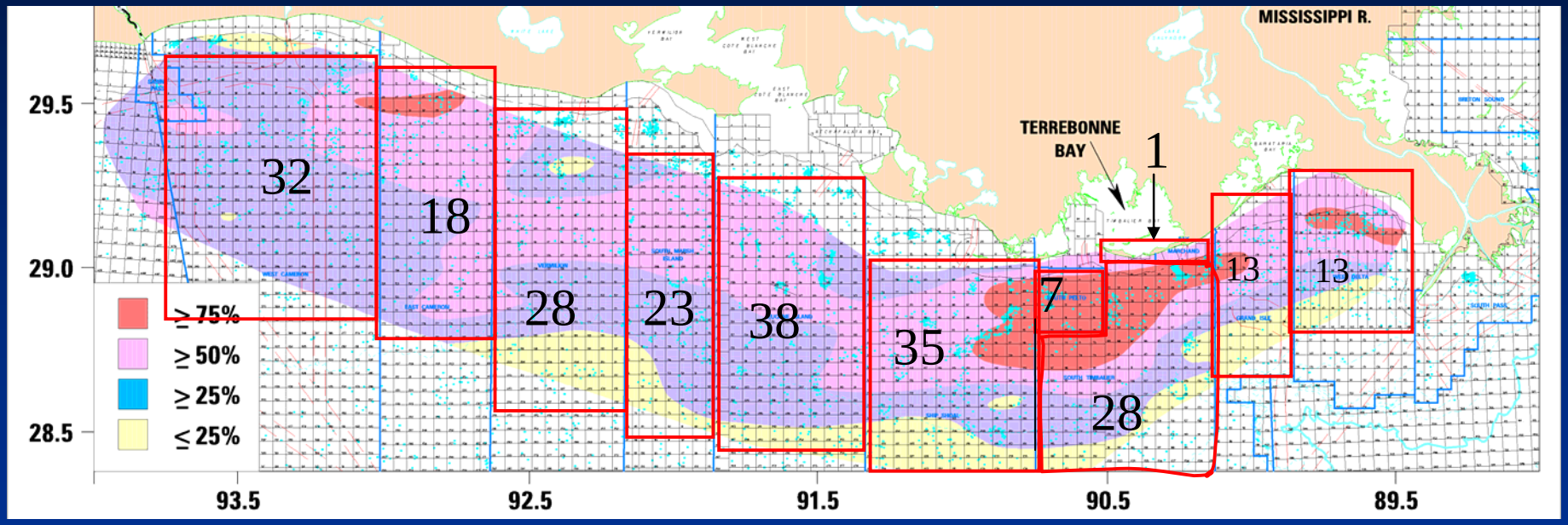


Goolsby et al. 1999

Study Approach

- Use estimated produced water loads developed by Veil et al. (2005).
- Conduct predictive simulations with three existing models of Gulf hypoxia using produced water and MRB loads.
- Compare predictions to results of original models with only MRB loads.
- Report incremental impacts in terms of percent and absolute changes.

Oil and Gas Platforms in Hypoxic Zone



J. P. Smith, ExxonMobil

Contributions of PW Loads

Parameter	Mean Daily Loads from MRB to Gulf of Mexico, 1980-1996 (adapted from Goolsby et al. 1999) (lbs/day)	Estimated Mean Daily Loads from Produced Waters to Gulf of Mexico Hypoxic Zone (adapted from Veil et al. 2005) (lbs/day)	Percent Contributions of Produced Waters
Total N	9,470,000	15,061	0.16
Nitrate N	5,750,000	197	0.003
Ammonia N	187,000	13,804	7.38
Total P	824,000	109	0.013
Orthophosphate P	252,000	65	0.026

Three Existing Models

- Bierman et al. (1994)
  - Eutrophication model (N, P and Si)
  - 3D
  - Summer steady state
- Justić et al. (1996)
  - Oxygen flux model (Nitrogen)
  - Two vertical layers in core of hypoxic zone (Station C6)
  - Monthly time variable
- Scavia et al. (2003)
  - Oxygen flux model (Nitrogen)
  - 1D horizontal downstream of riverine inputs
  - Summer steady state

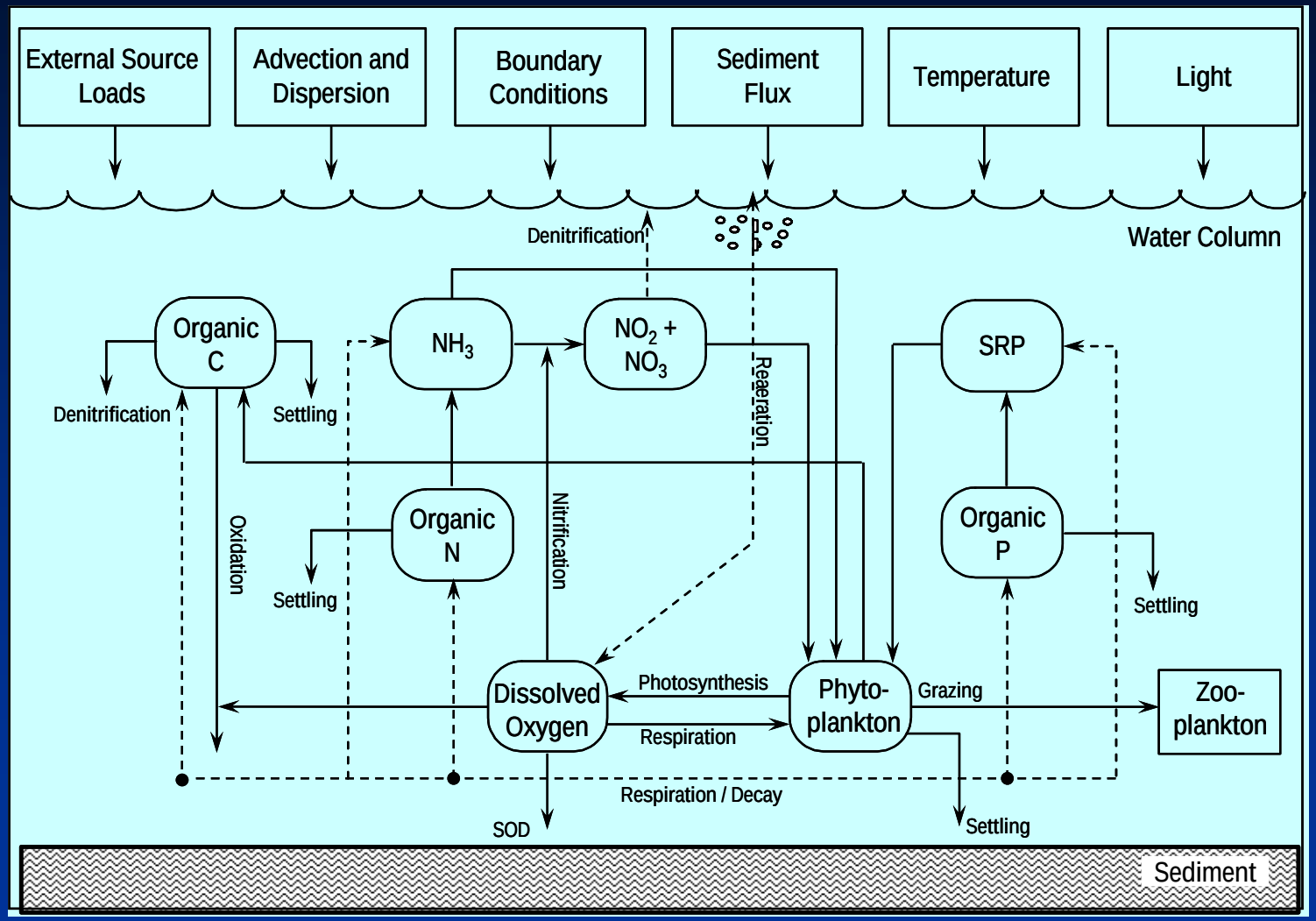
Principal Model Attributes

Attribute	MODEL		
	Bierman	**Justić**	**Scavia**
General Description	Moderately complex mechanistic eutrophication model	Simple two-layer dissolved oxygen model	Simple dissolved oxygen model for bottom waters
Spatial Scale	3D with 21 spatial segments in hypoxic zone	1D vertical at Station C6 in core of hypoxic zone	1D horizontal in subpycnocline downstream of river inputs
Temporal Scale	Summer Steady-State	Monthly Time-Variable	Summer Steady-State
Nutrients	Phosphorus, nitrogen and silicon	Nitrogen	Nitrogen
Hypoxia Characterization	3D structure of summer-average dissolved oxygen concentrations in hypoxic zone	Seasonal dynamics of dissolved oxygen concentrations in core of hypoxic zone	Interannual variability in hypoxic zone length and area
Calibration Time Periods	1985, 1988 and 1990	1985-1993	1985-2002

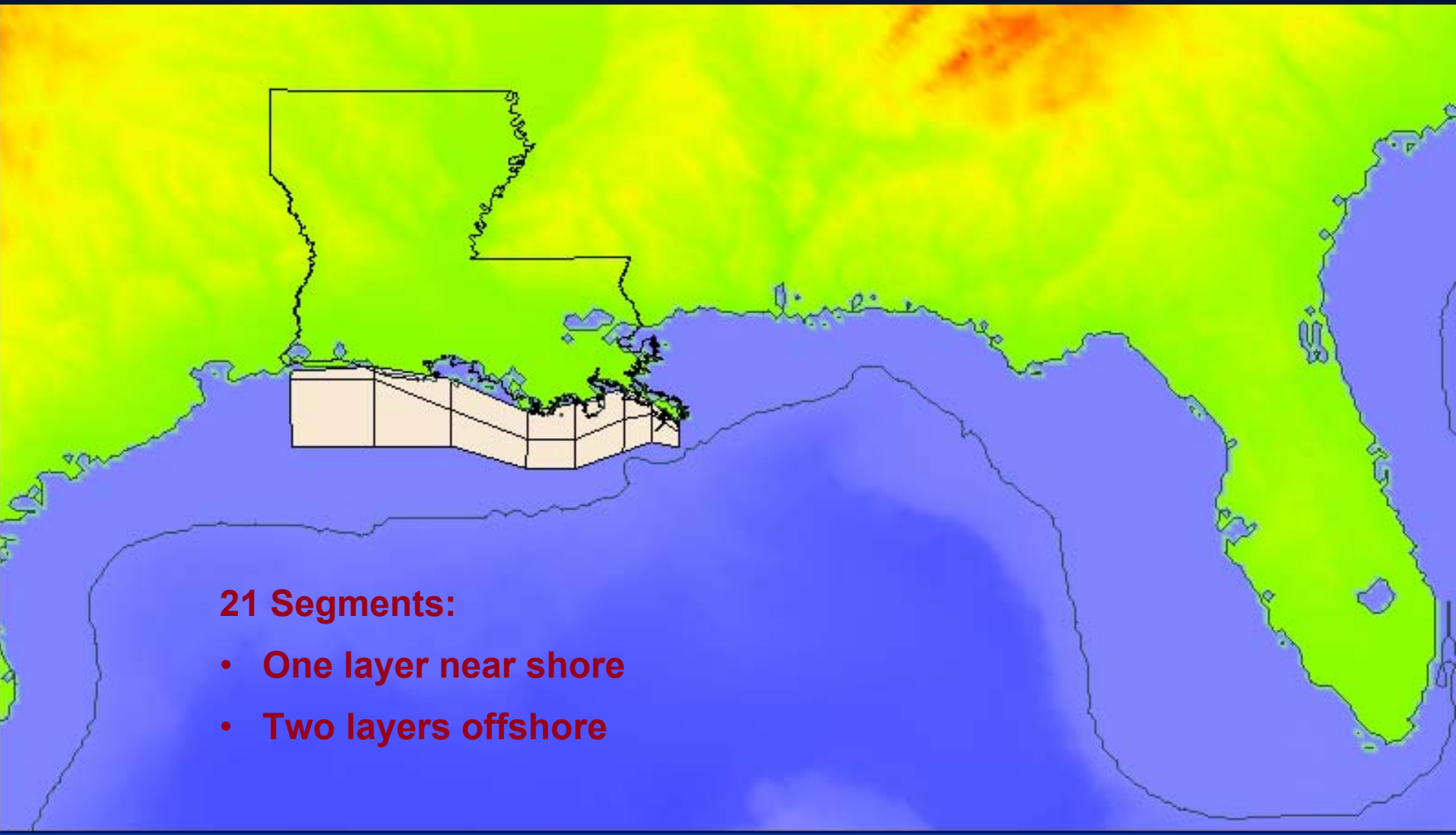
Model State Variables

State Variables	MODEL		
	Bierman	**Justić**	**Scavia**
Dissolved Oxygen	X	X	X
Biochemical Oxygen Demand (BOD)	X		X
Sediment Organic Carbon		X	
Salinity	X		
Algal Carbon	X		
Phosphate Phosphorus	X		
Organic Phosphorus	X		
Ammonium Nitrogen	X		
Nitrate/Nitrite Nitrogen	X		
Organic Nitrogen	X		

Bierman Model Framework



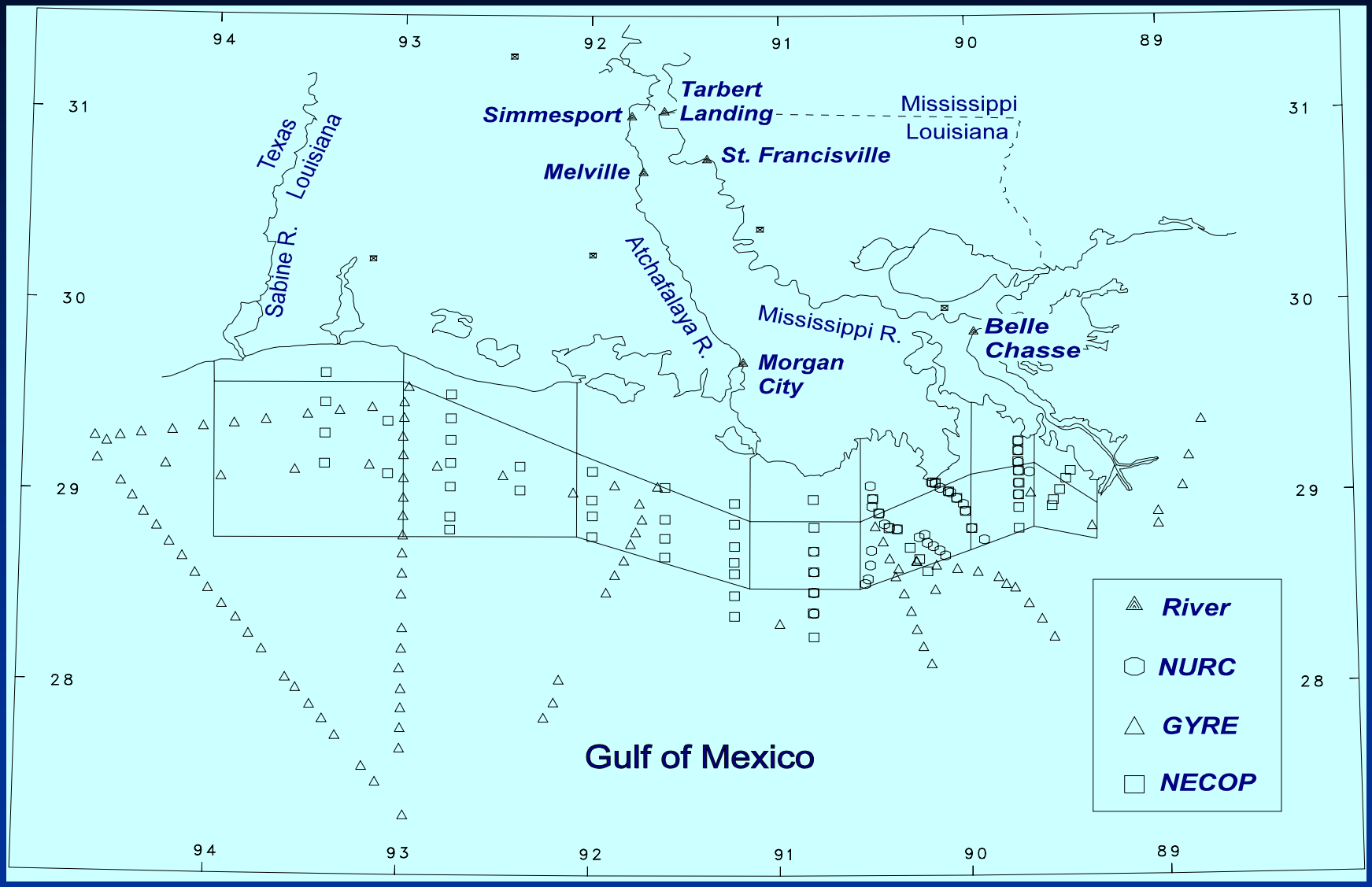
Bierman Model Spatial Grid
3D in Hypoxic Zone



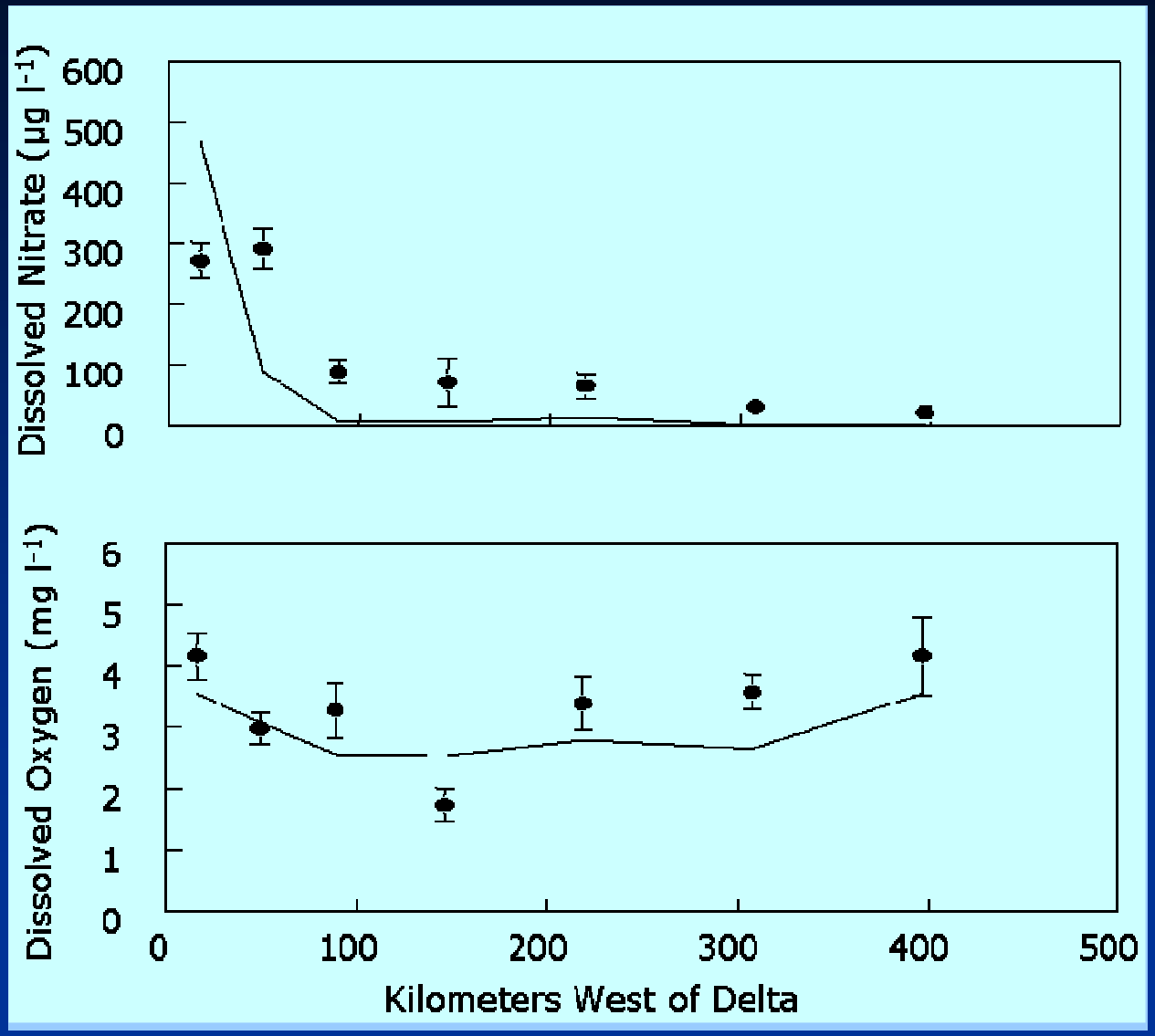
21 Segments:

- **One layer near shore**
- **Two layers offshore**

Bierman Model
July 1990 Calibration Stations

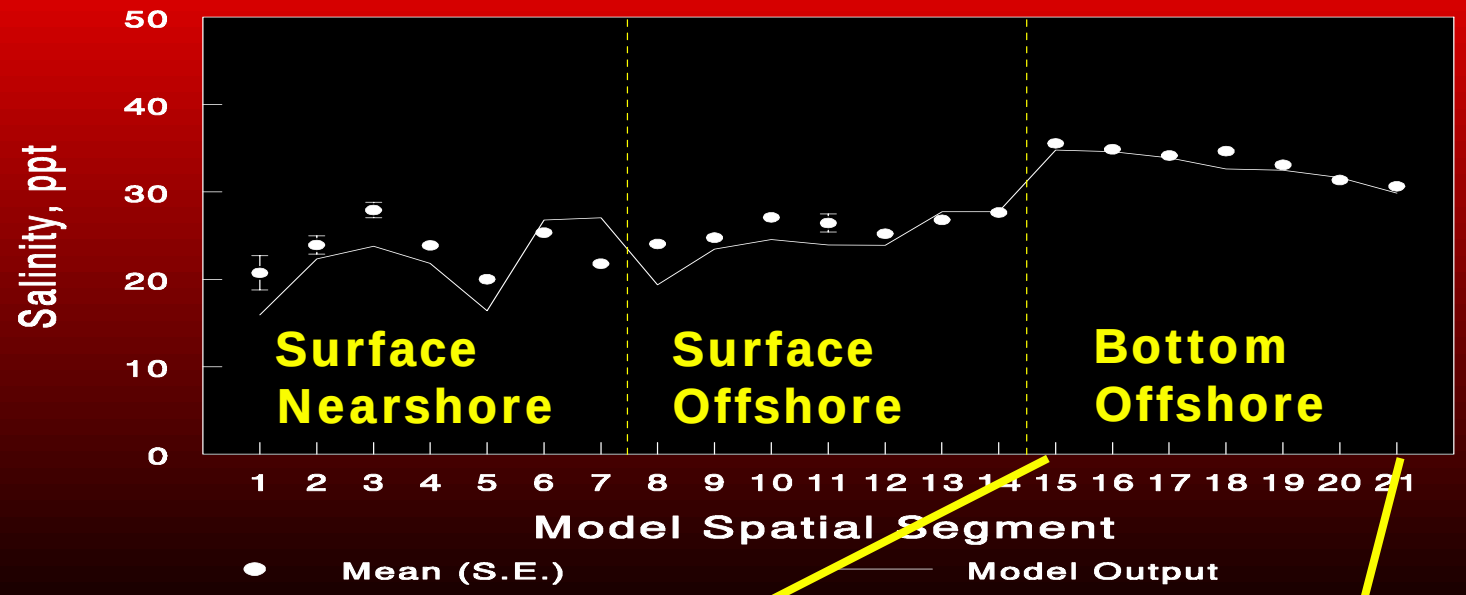


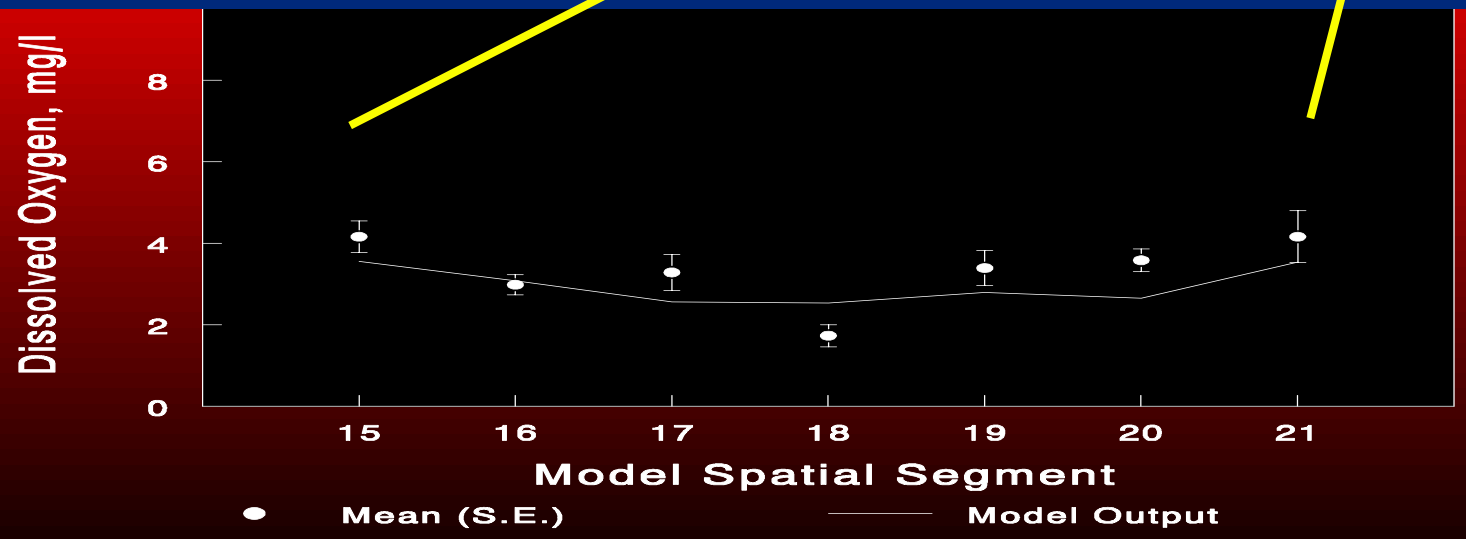
Bierman Model
Illustrative Calibration Results (1990)



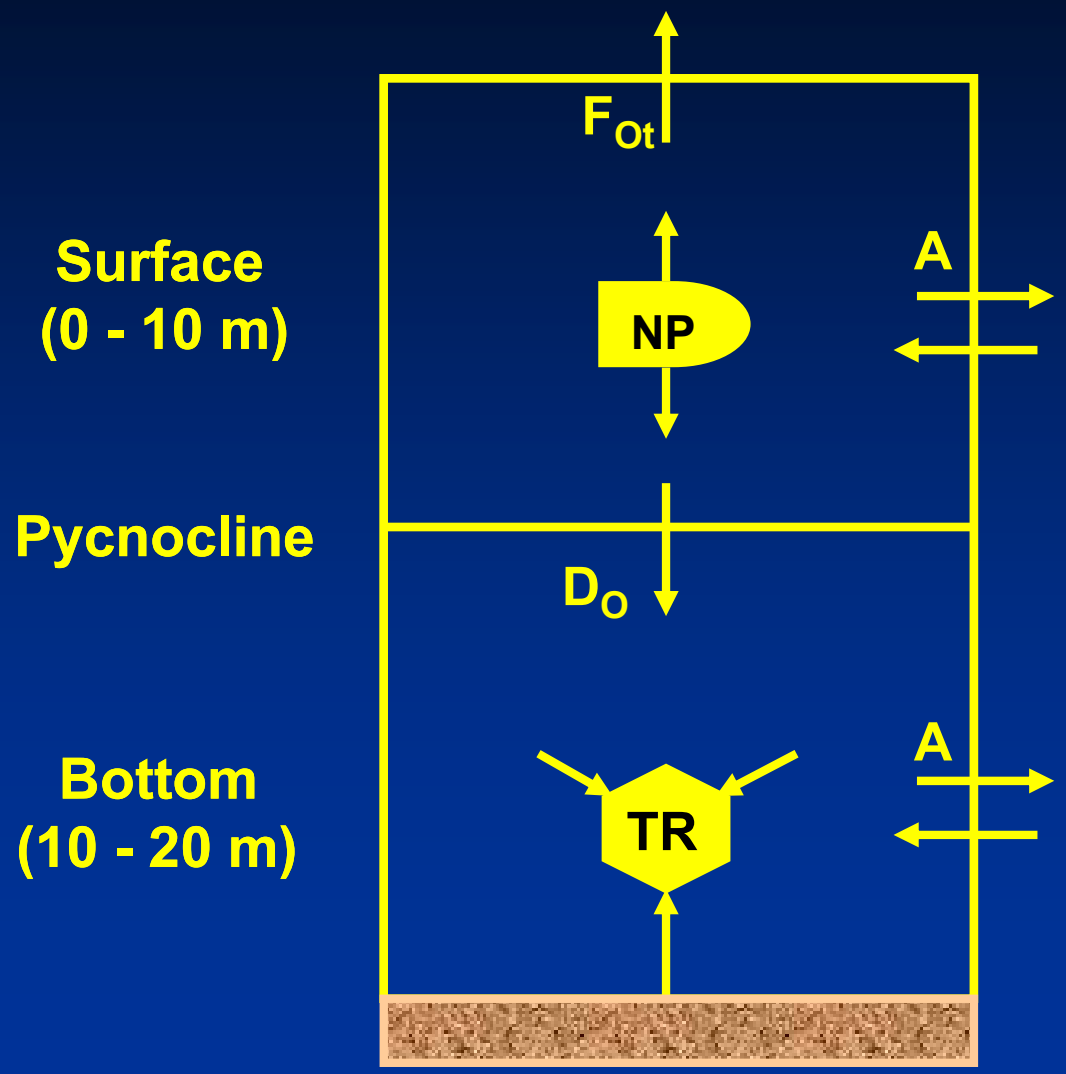
Louisiana Inner Shelf

Salinity - July 1990

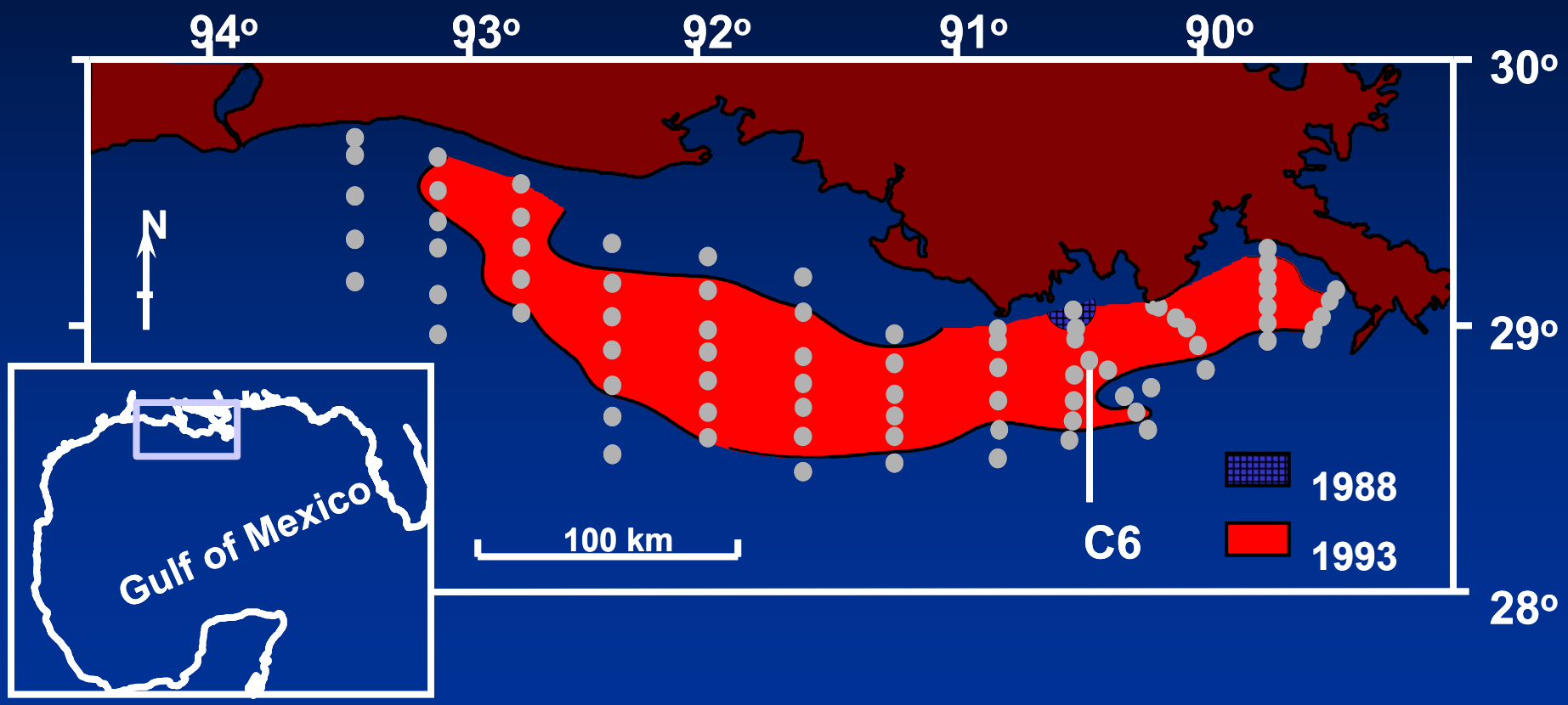




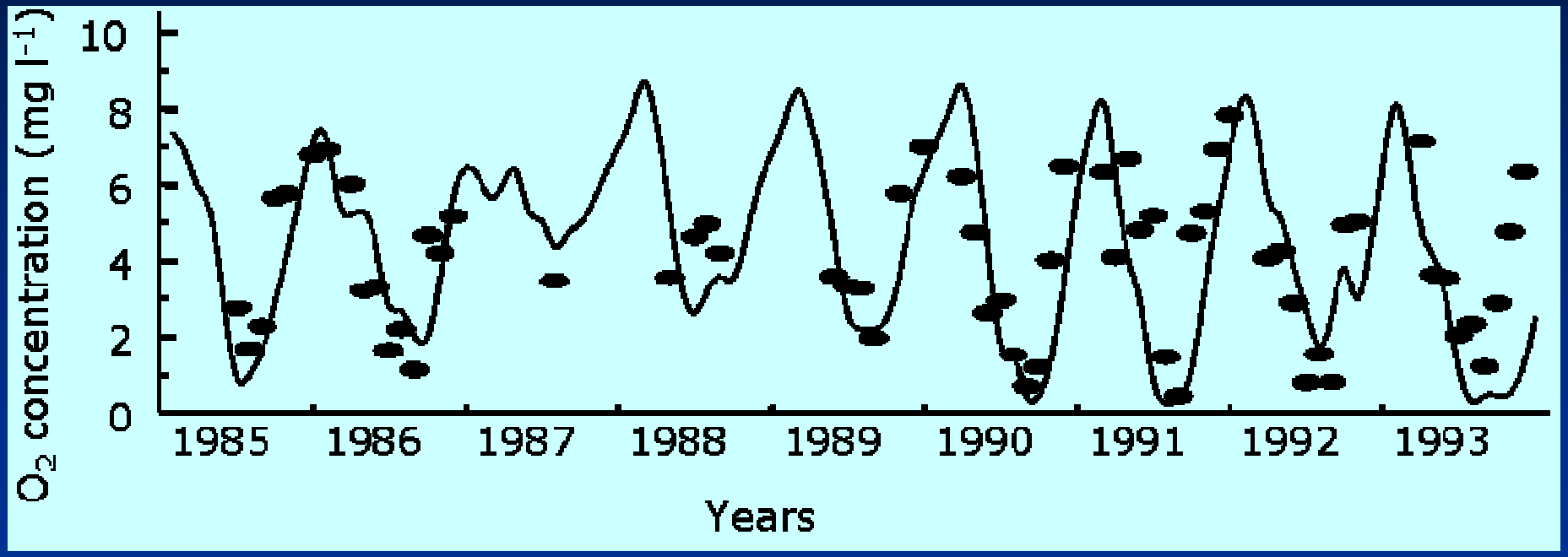
Justic Model Framework



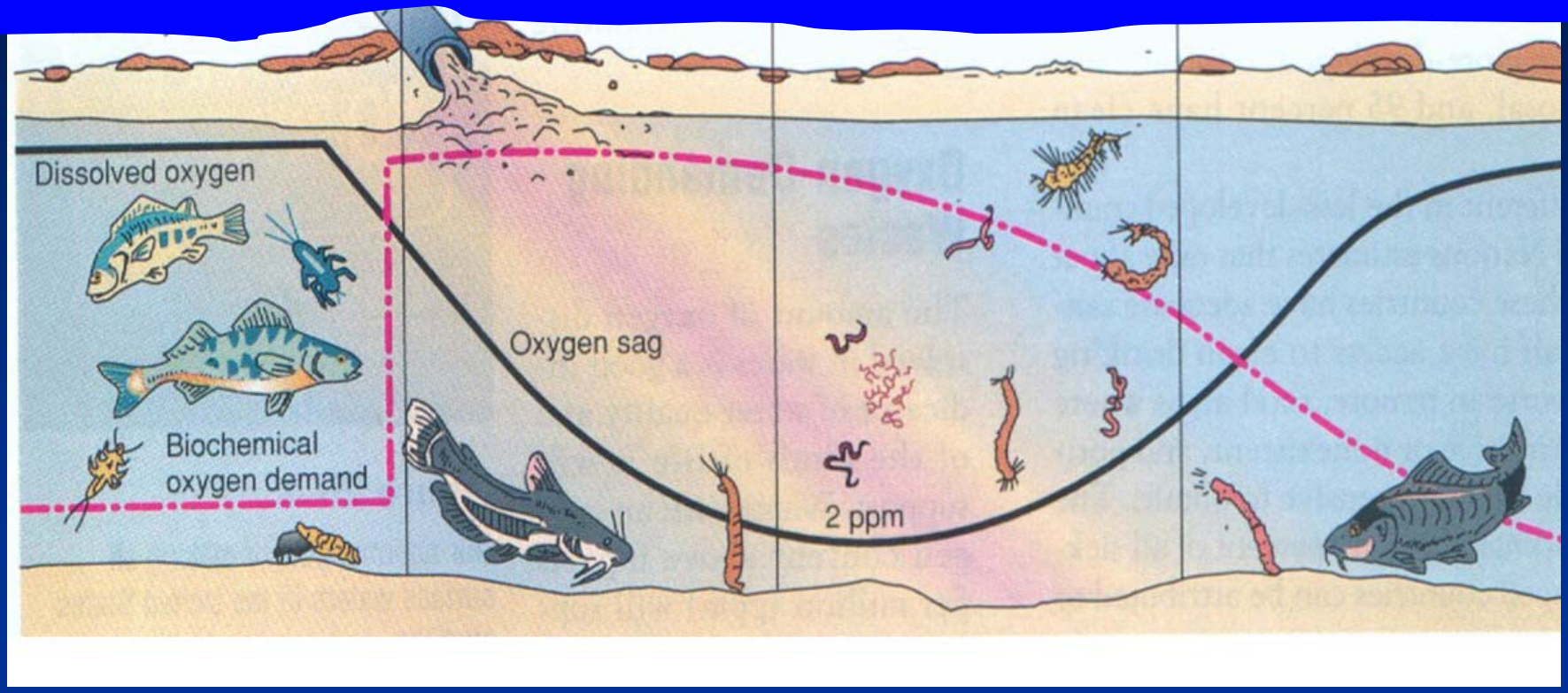
Justic Model Spatial Scale
Station C6 – Core of Hypoxic Zone



Justić Model Calibration
Bottom Waters



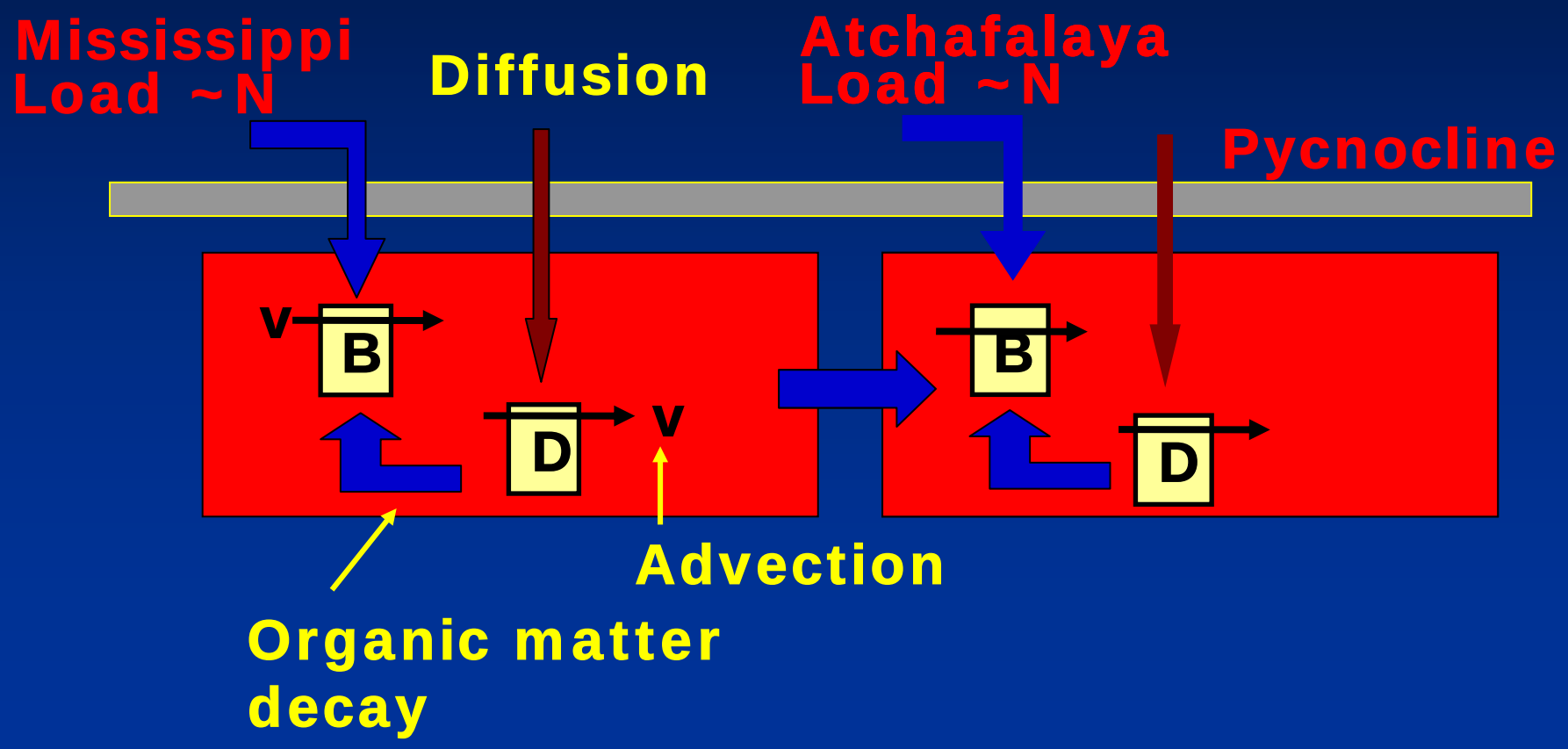
Scavia Model Pictorial
Downstream Flow Line Along Bottom Waters



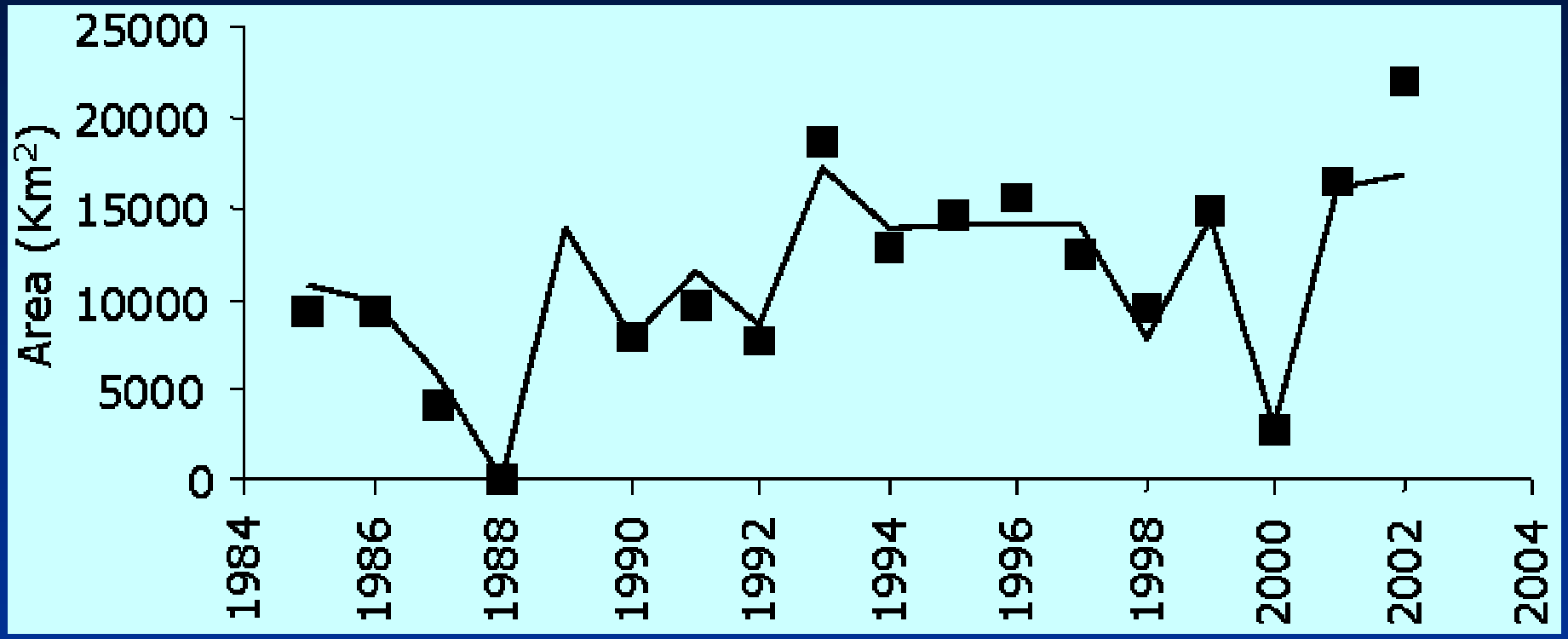
Scavia Model Framework

B = Organic Matter

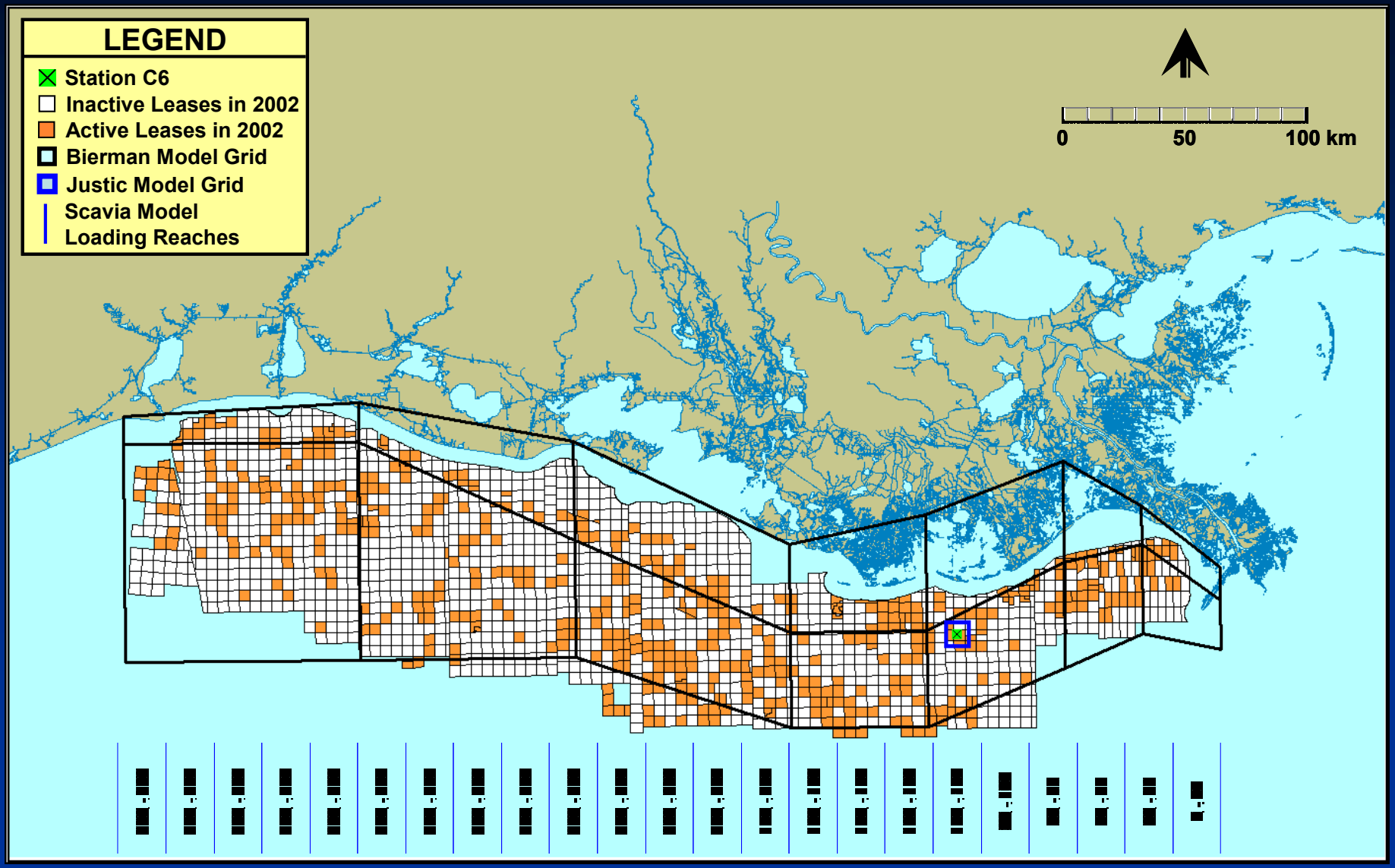
D = Dissolved Oxygen



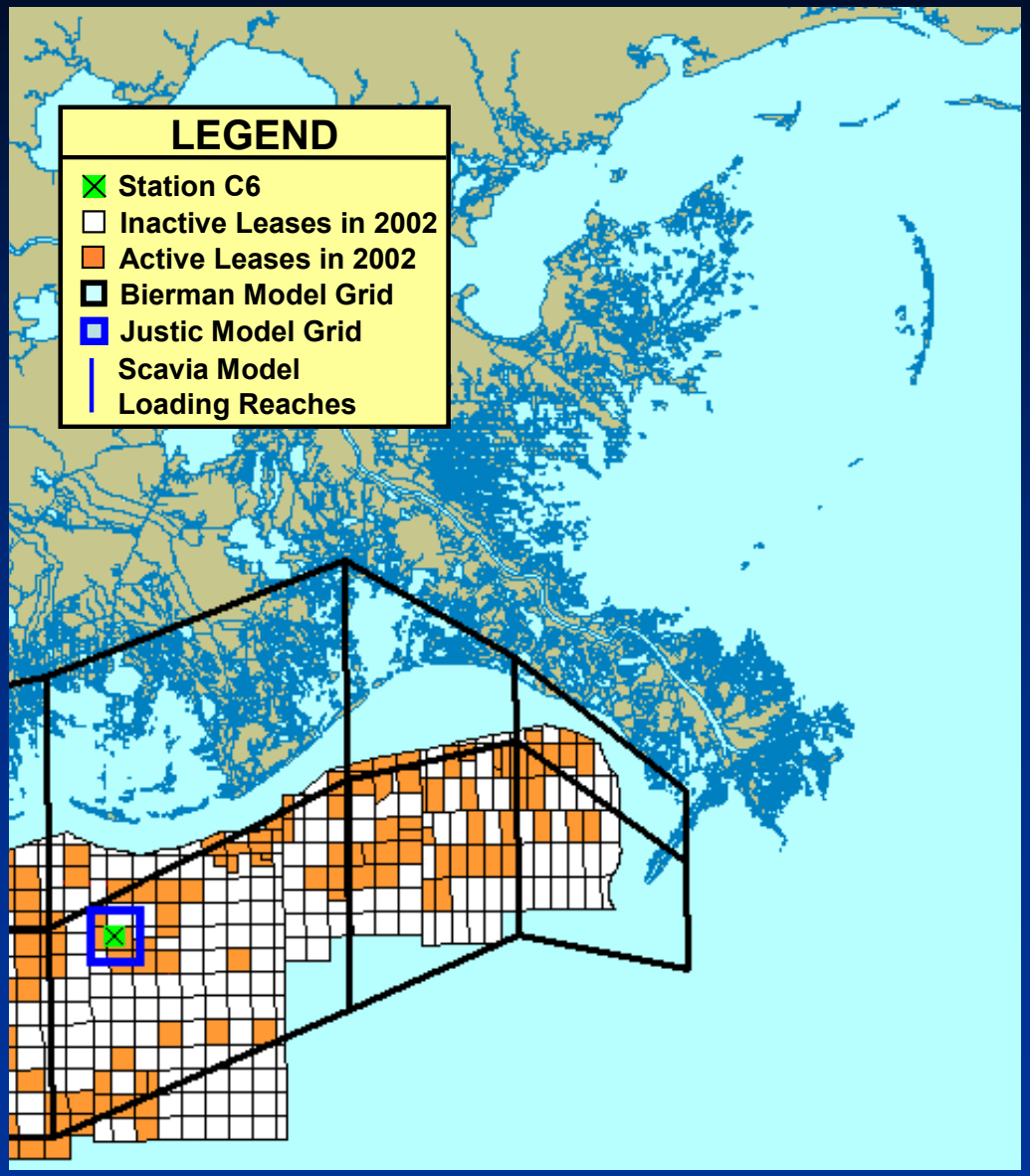
Scavia Model Calibration



Study Domain



Spatial Detail Near Station C6



Delivery Locations for PW Loads

- Bierman Model
  - Total PW loads apportioned among 21 individual model segments
- Justić Model
  - Mississippi River delta
    - Only PW loads between delta and Station C6
  - 10 x 10 Km grid centered on Station C6
    - Only PW loads within this grid
- Scavia Model
  - Total PW loads apportioned between Mississippi and Atchafalaya Rivers
  - Total PW loads apportioned at 20 Km intervals along spine of hypoxic zone

Assumptions – All Models

- All PW generated from each lease block is actually discharged.
- $BOD_U = 1.25 \times BOD_5$
- "Suspended phase" fractions of BOD and TOC are 15%.
- 68% of total PW volume is discharged to surface waters (0–10 meters).
- 32% of total PW volume is discharged to bottom waters (below 10 meters).

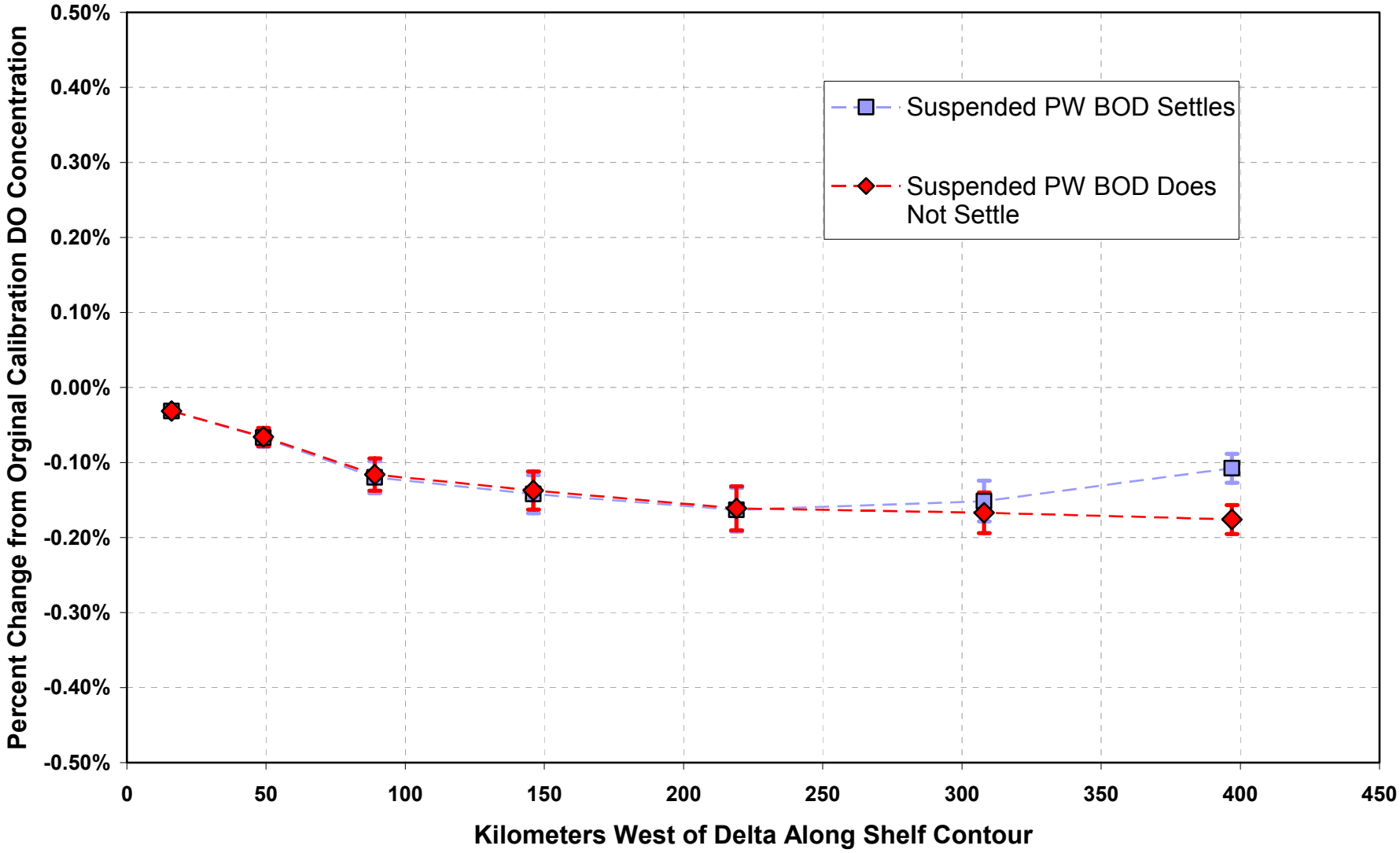
Bounding Simulations – All Models

- Settleability of “suspended phase” BOD and TOC in PW loads
  - Suspended phase settles (100% settles)
  - Suspended phase not settle (0% settles)
- Magnitudes of PW loads
  - Base loads as reported in Veil et al. (2005)
  - Lower and upper 95% confidence intervals

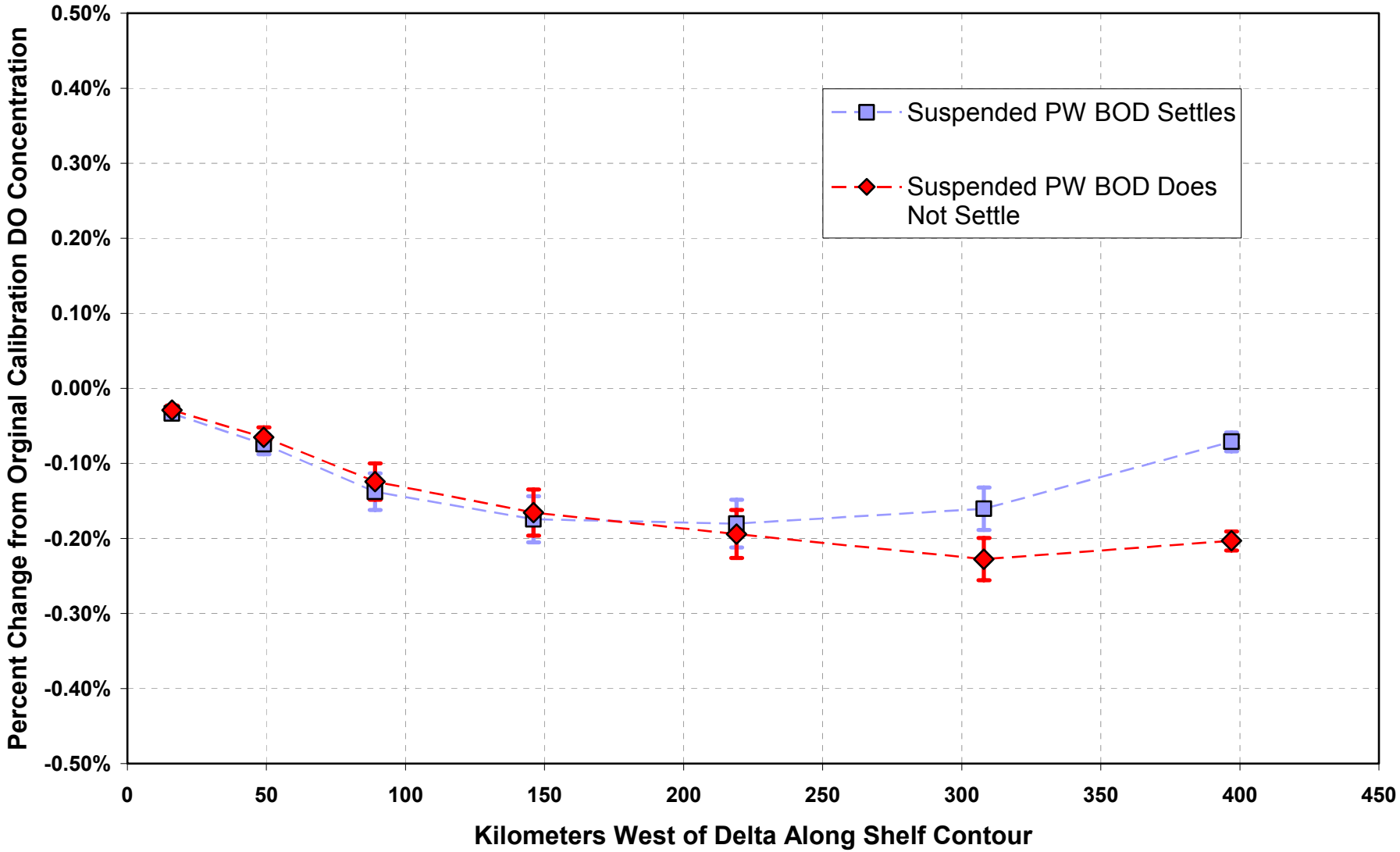
Bierman Model Summary Results

	Produced Water (PW) Loads		
Scenario	**Base**	**Lower Bound**	**Upper Bound**
1985			
Suspended PW BOD Settles	-0.110	-0.091	-0.130
Suspended PW BOD Does Not Settle	-0.118	-0.099	-0.138
1988			
Suspended PW BOD Settles	-0.118	-0.097	-0.139
Suspended PW BOD Does Not Settle	-0.138	-0.117	-0.159
1990			
Suspended PW BOD Settles	-0.201	-0.165	-0.237
Suspended PW BOD Does Not Settle	-0.143	-0.107	-0.179

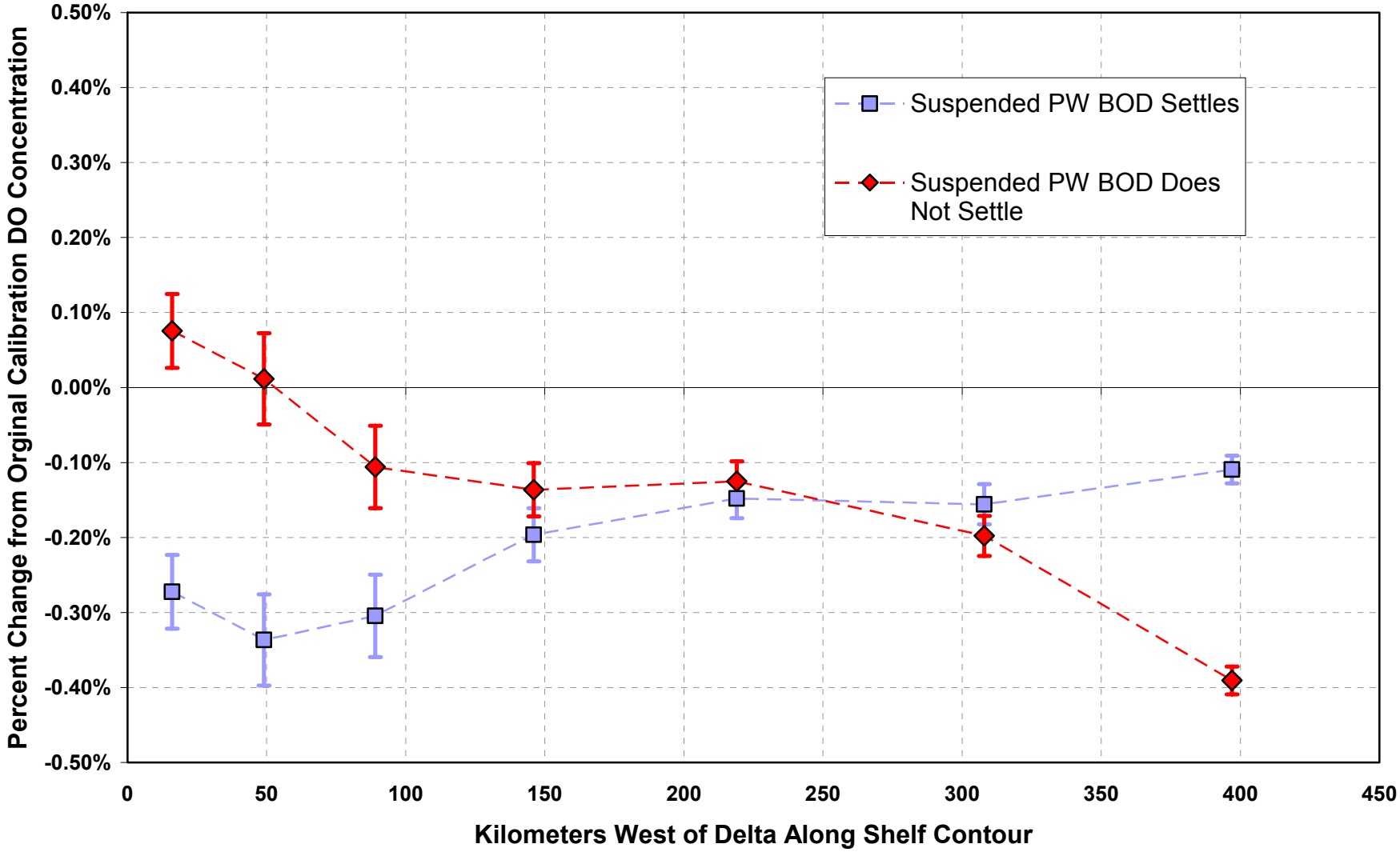
Bierman – Summer 1985



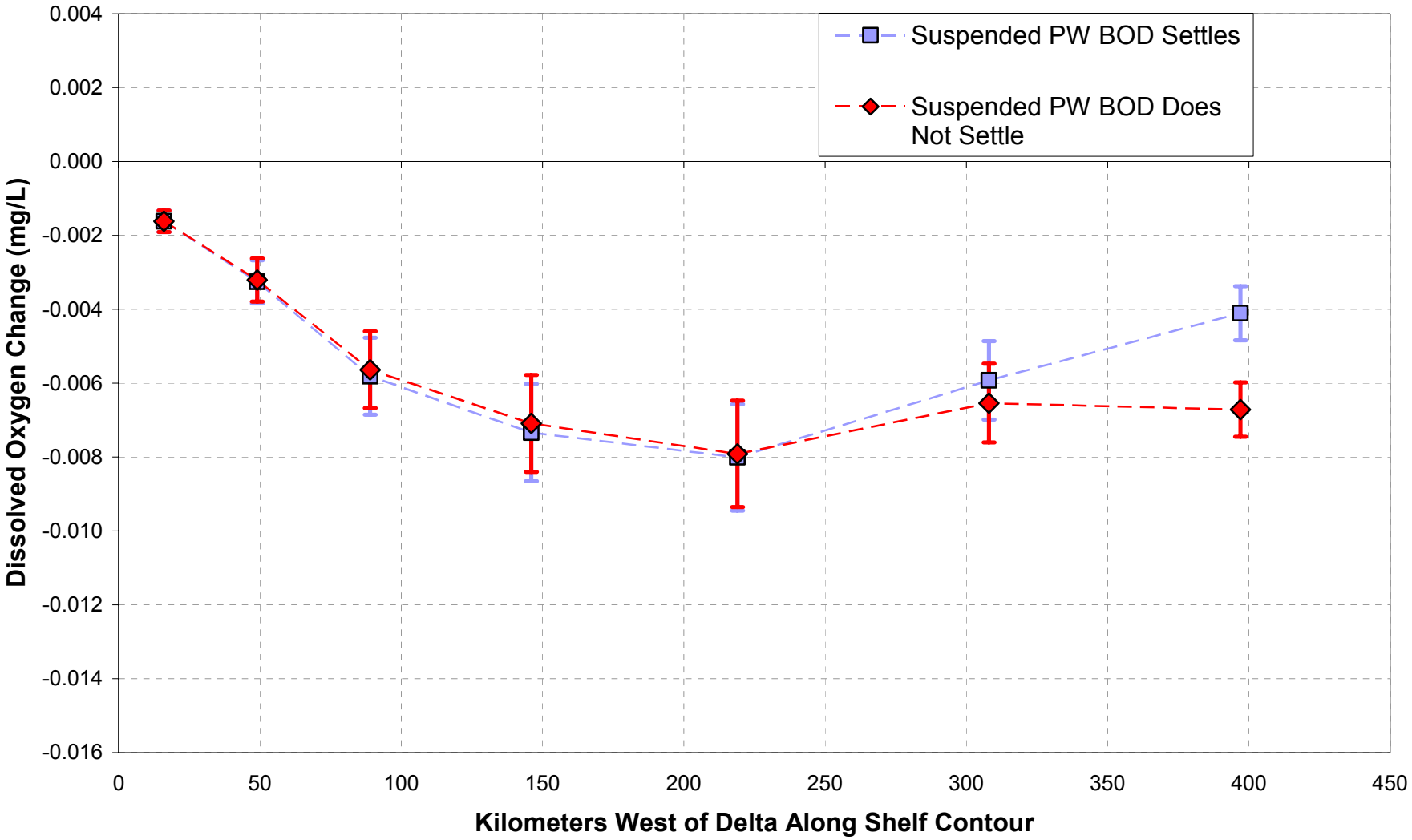
Bierman – Summer 1988



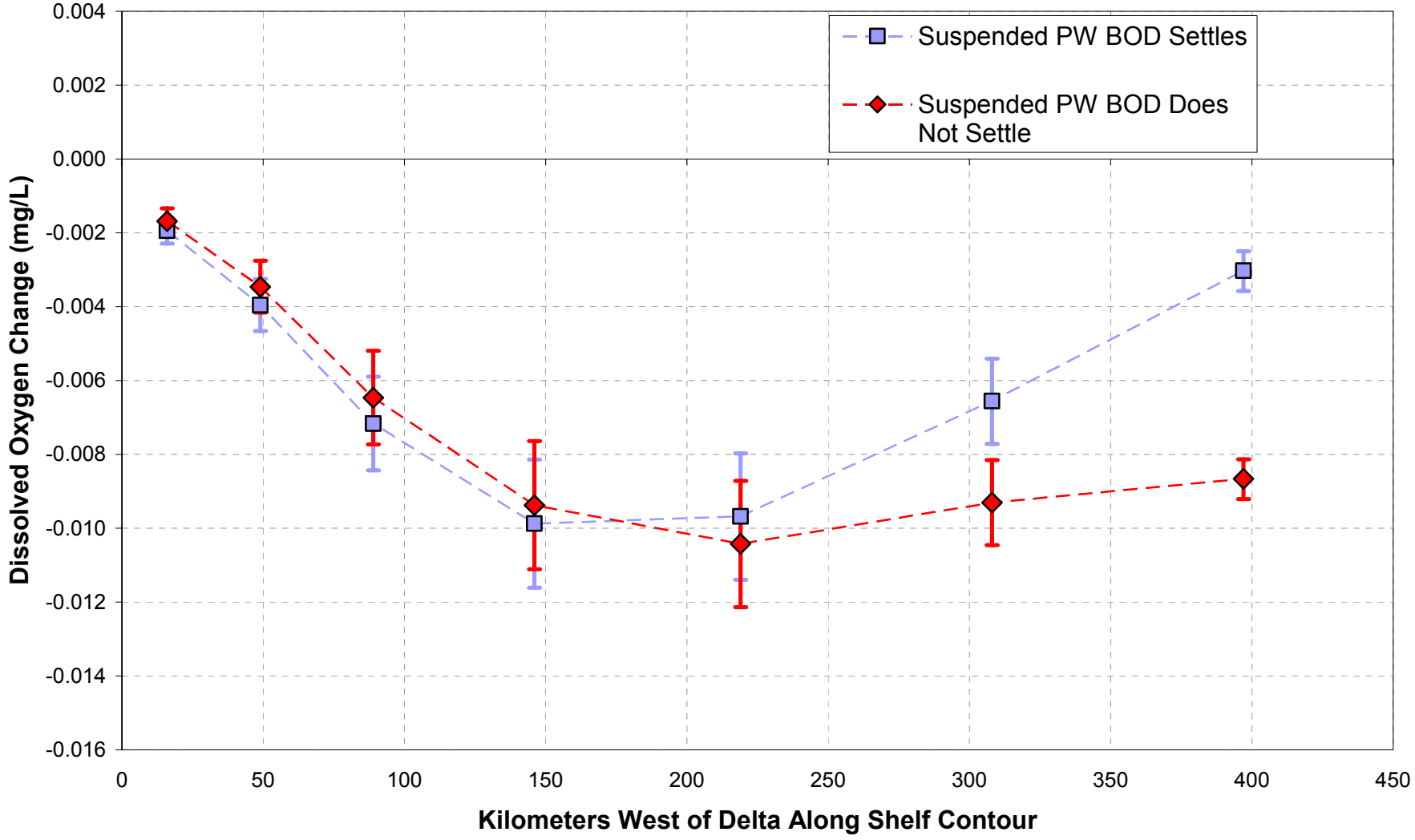
Bierman – Summer 1990



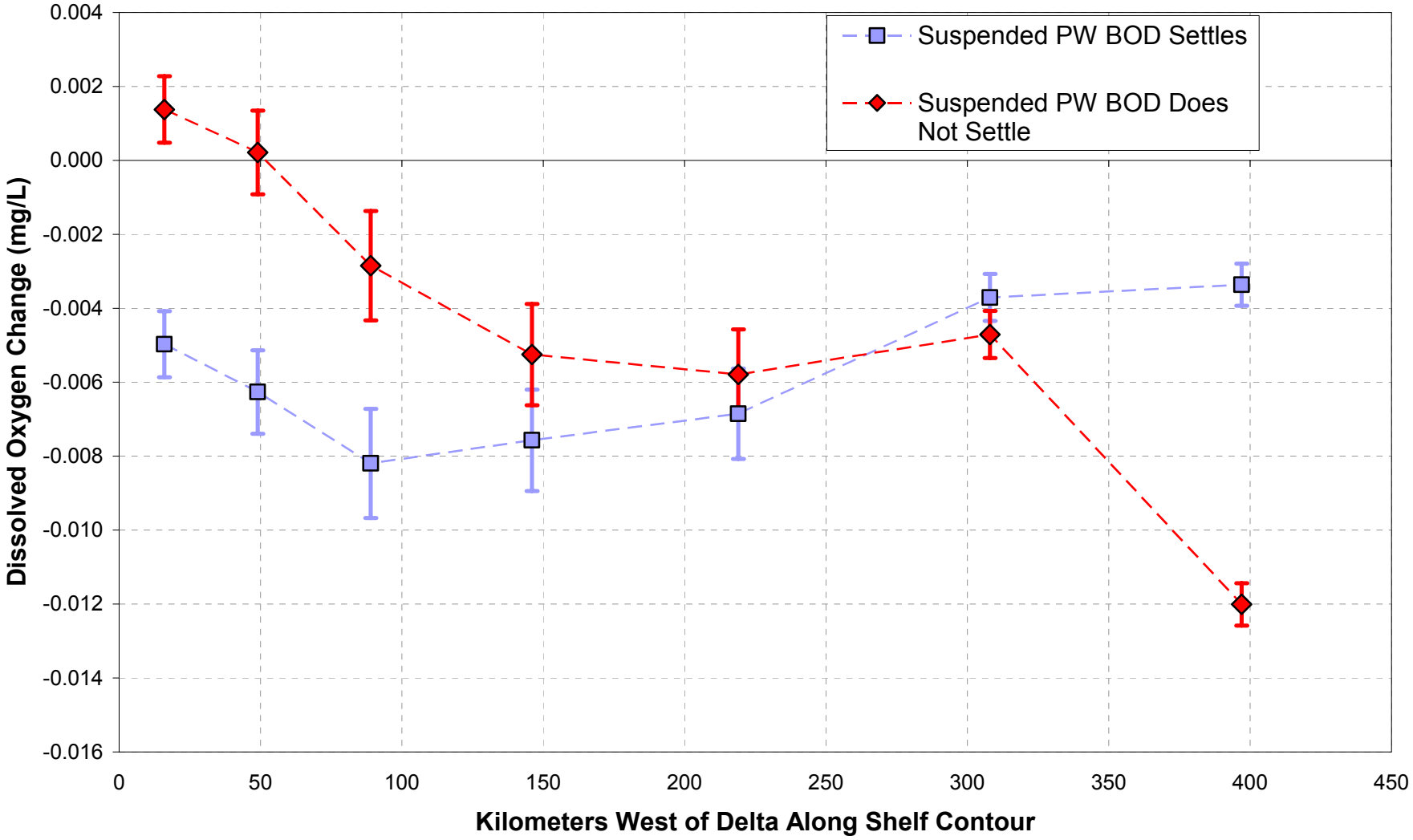
Bierman – Summer 1985



Bierman – Summer 1988



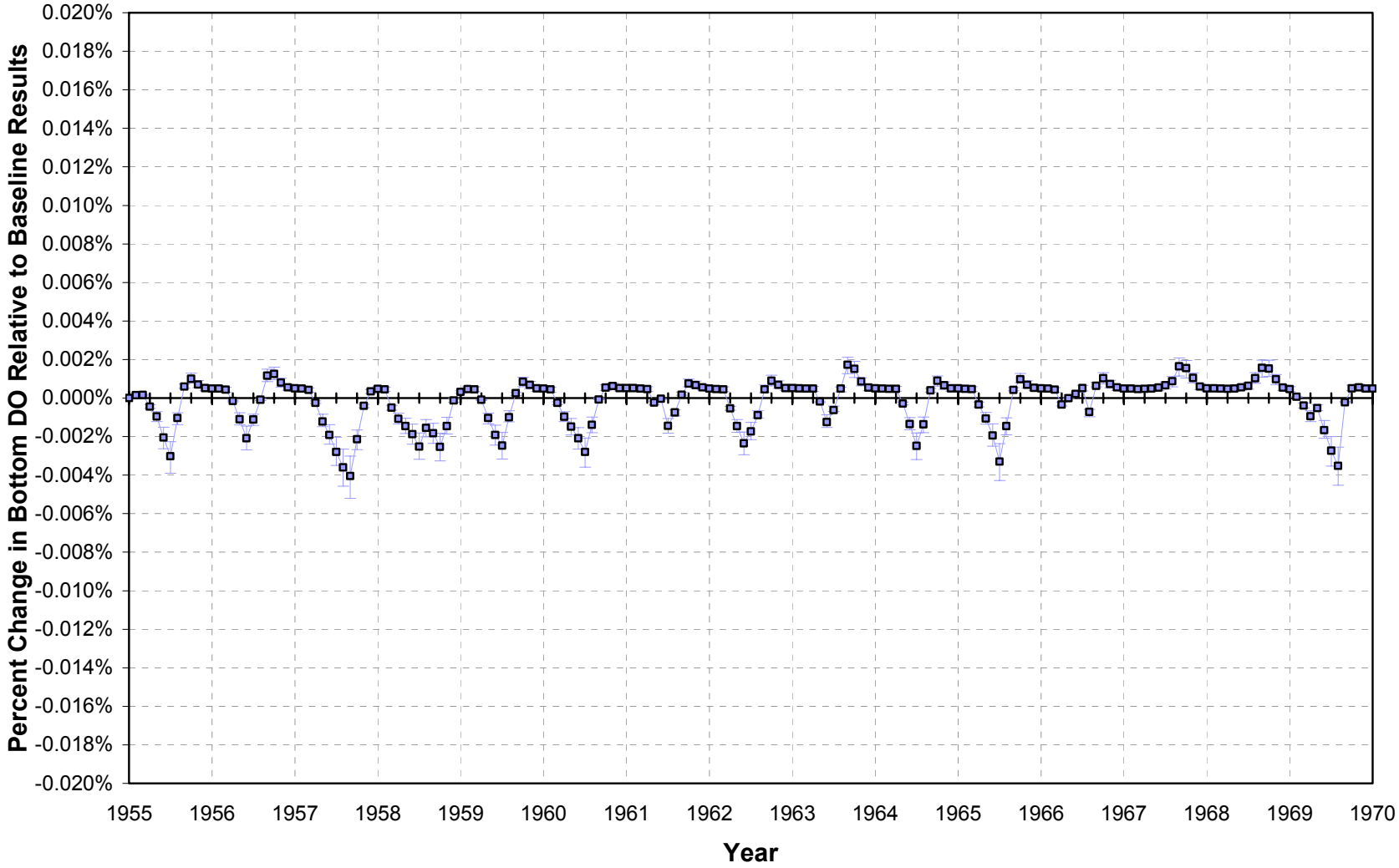
Bierman – Summer 1990



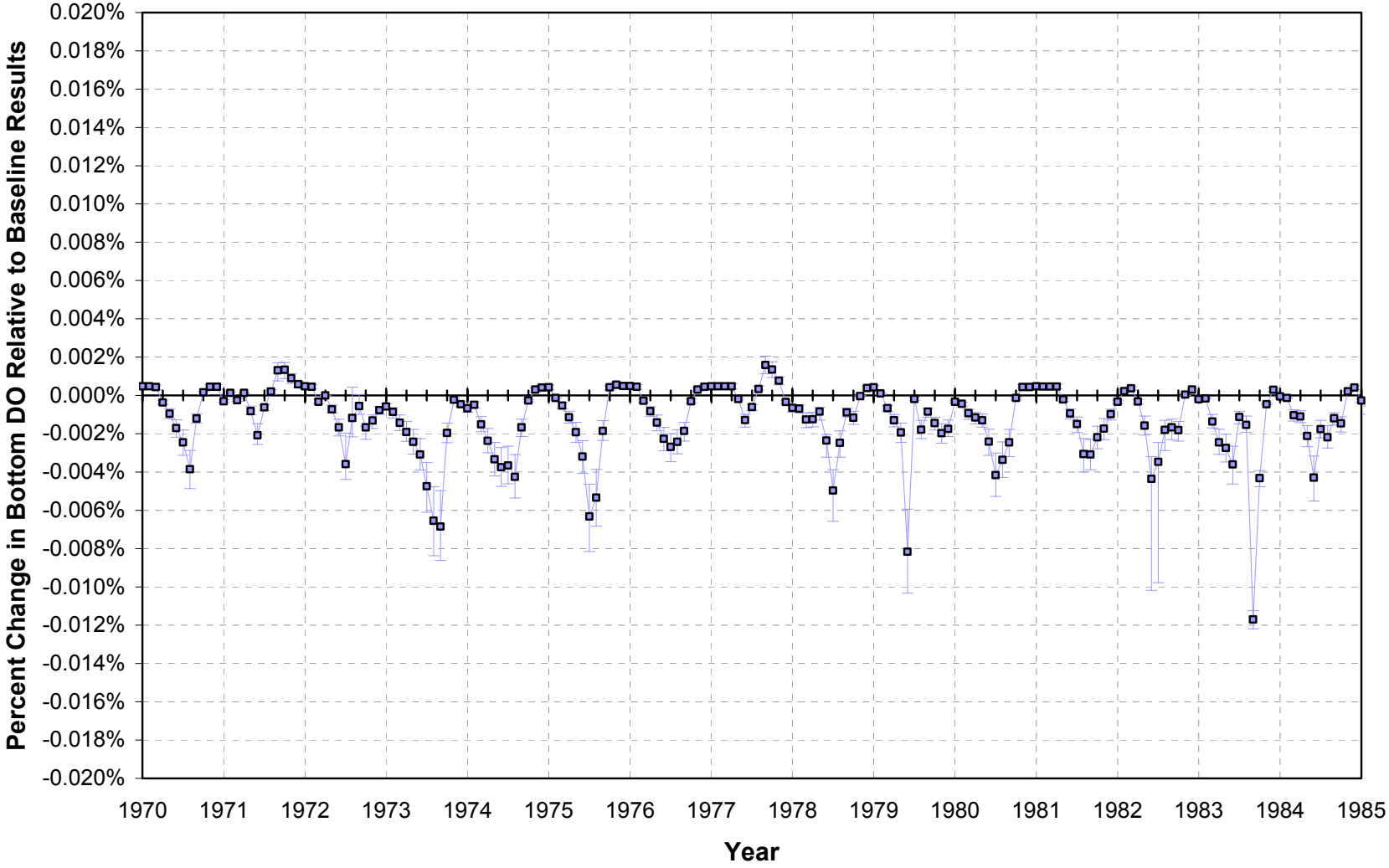
Justić Model Summary Results

	Produced Water (PW) Loads		
Scenario	**Base**	**Lower Bound**	**Upper Bound**
PW Loads (Nitrate Nitrogen) Delivered at Mississippi Delta			
Suspended PW TOC Settles	-0.0023	-0.0017	-0.0031
Suspended PW TOC Does Not Settle	N/A	N/A	N/A
PW Loads (Nitrate Nitrogen and TOC) Delivered at 10 x 10 Km Grid Centered on Station C6			
Suspended PW TOC Settles	-0.513	-0.368	-0.660
Suspended PW TOC Does Not Settle	-0.067	-0.049	-0.087

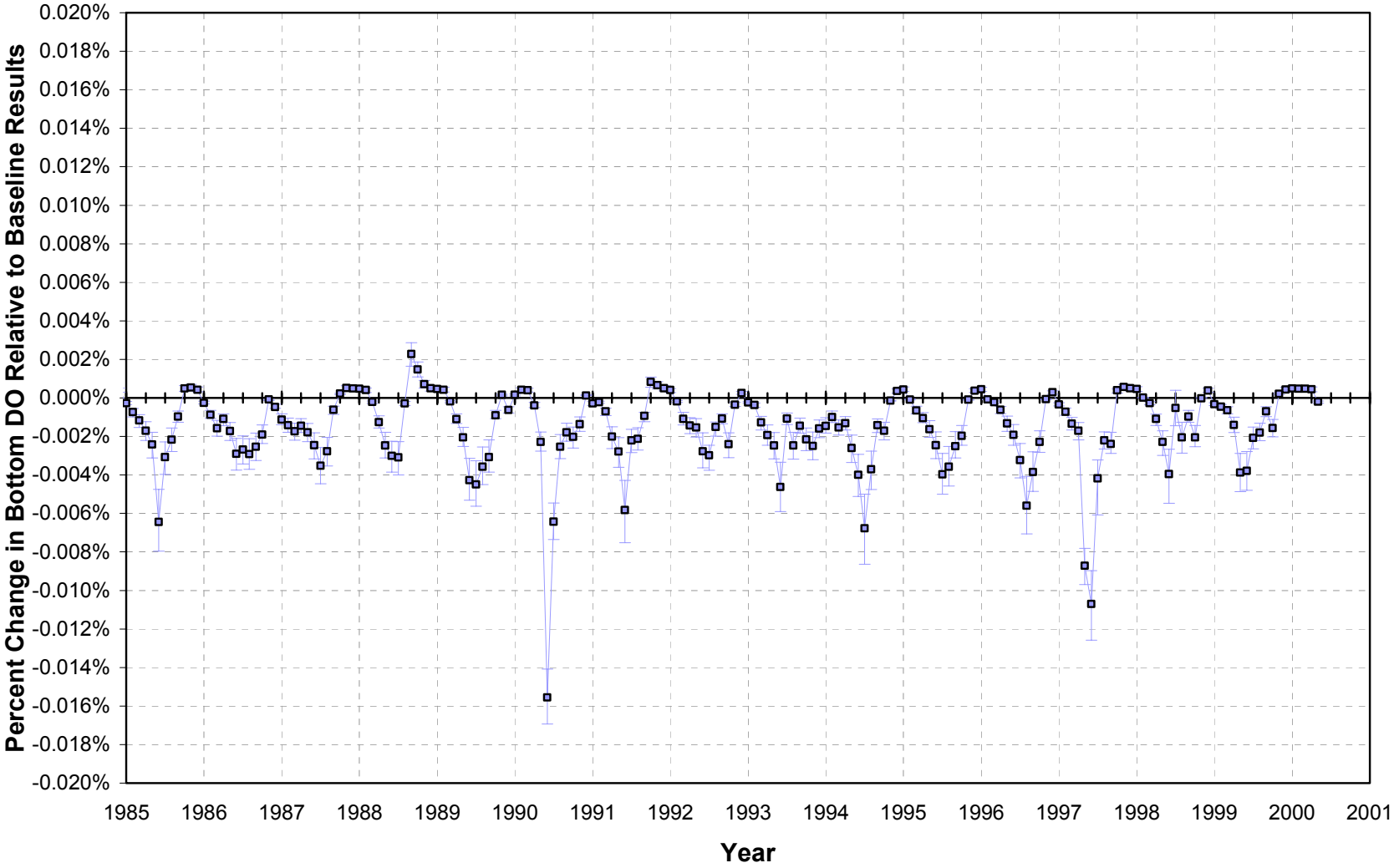
Justić – PW Delivered at Delta



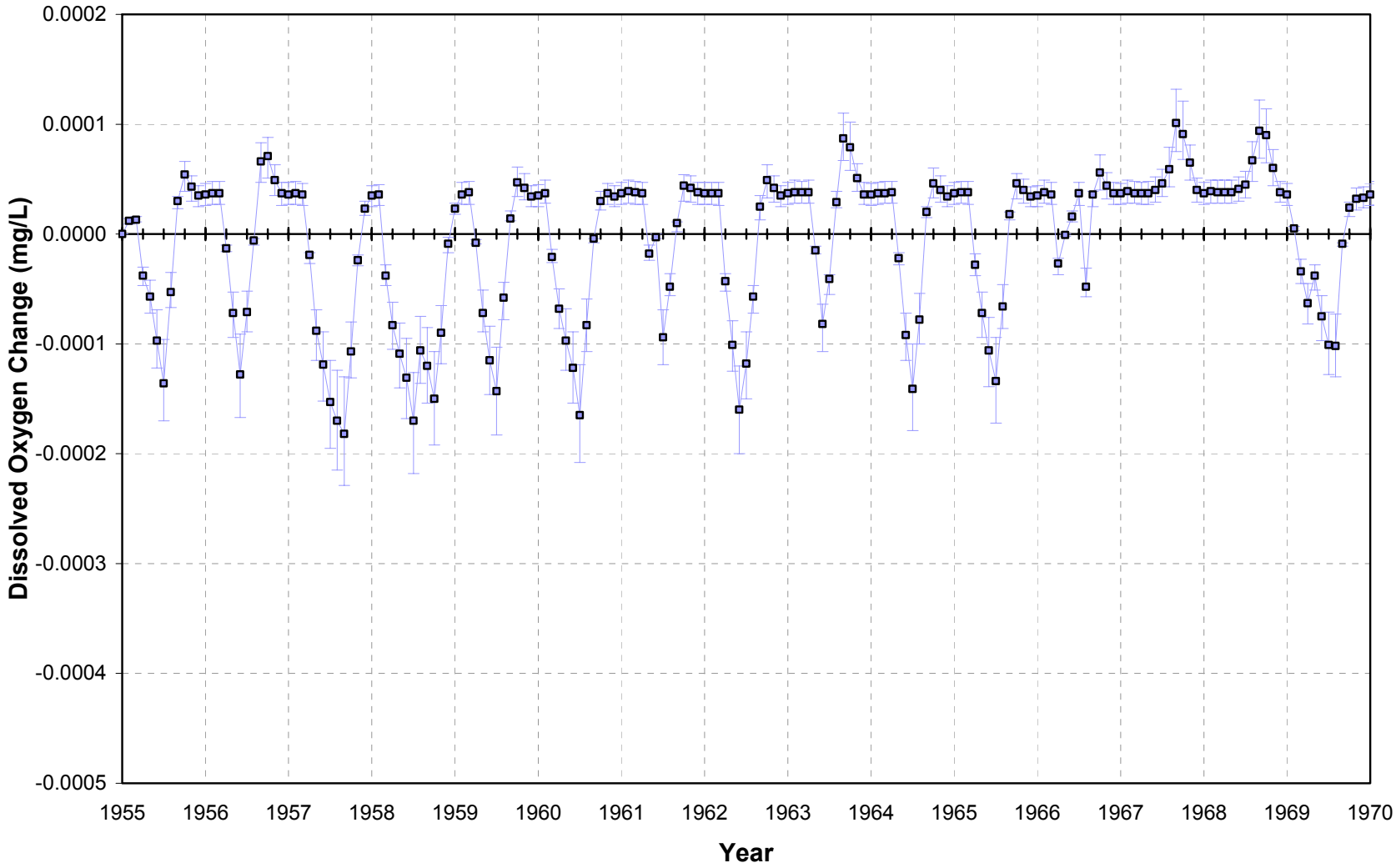
Justić – PW Delivered at Delta



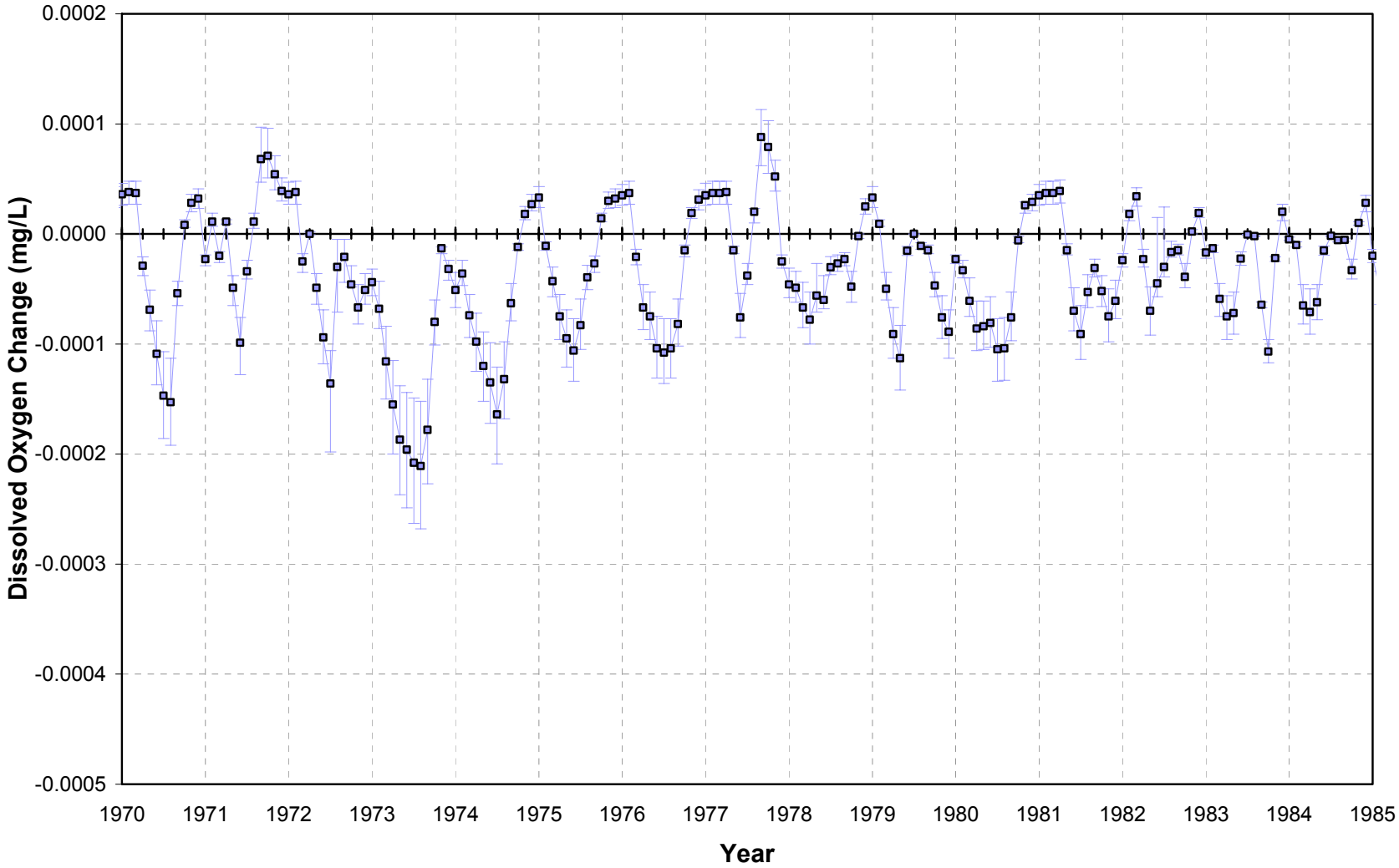
Justić – PW Delivered at Delta



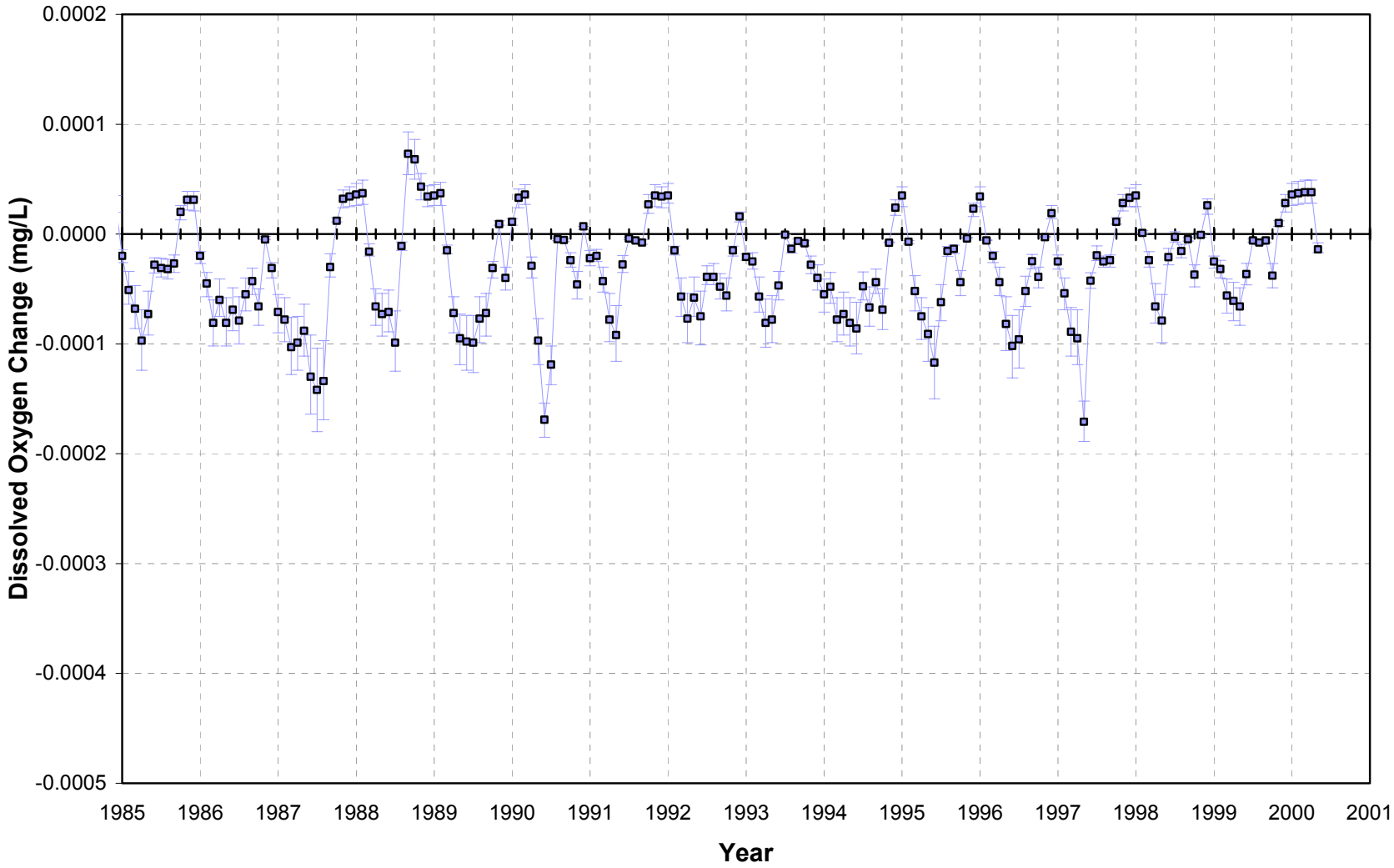
Justić – PW Delivered at Delta



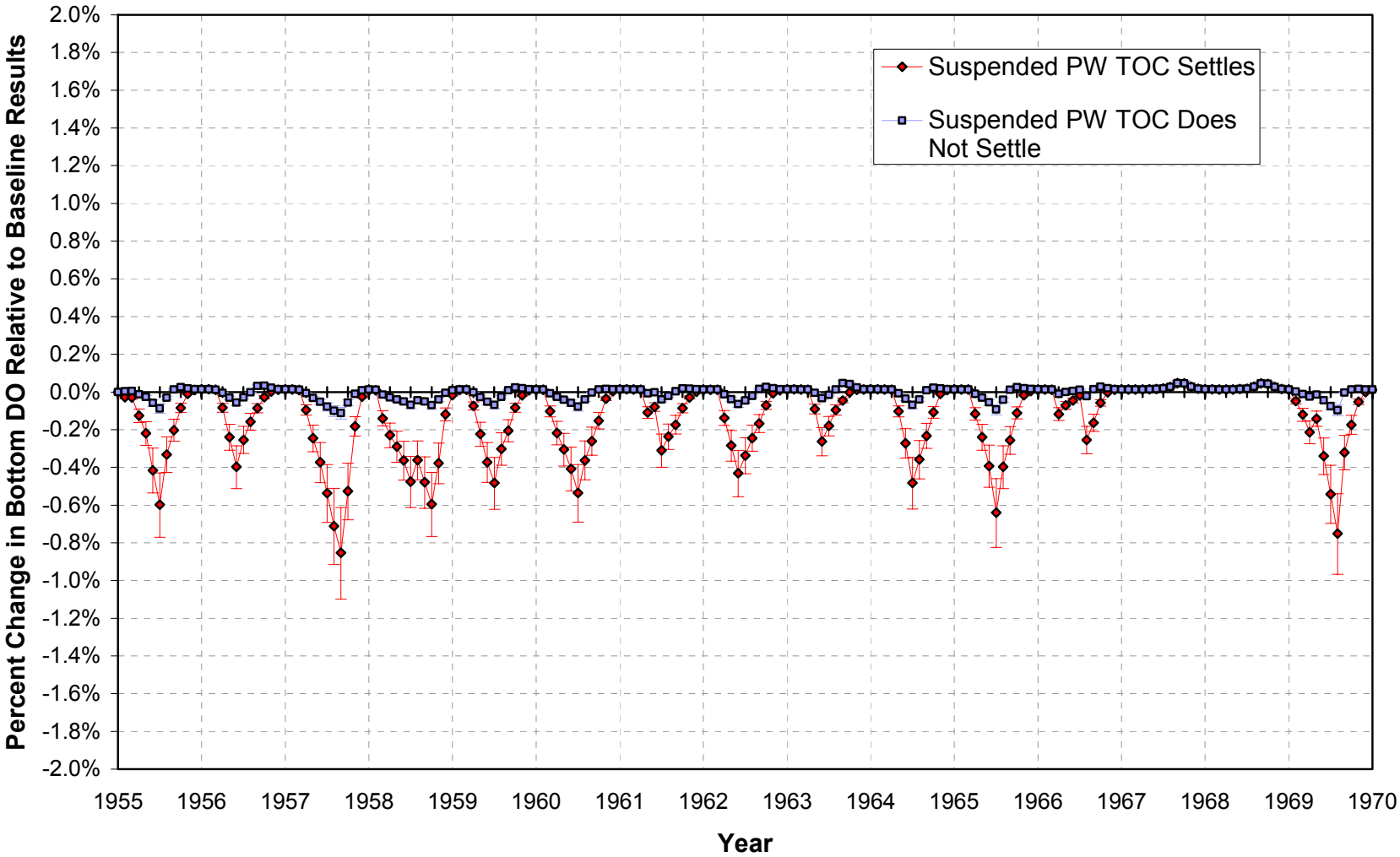
Justić – PW Delivered at Delta



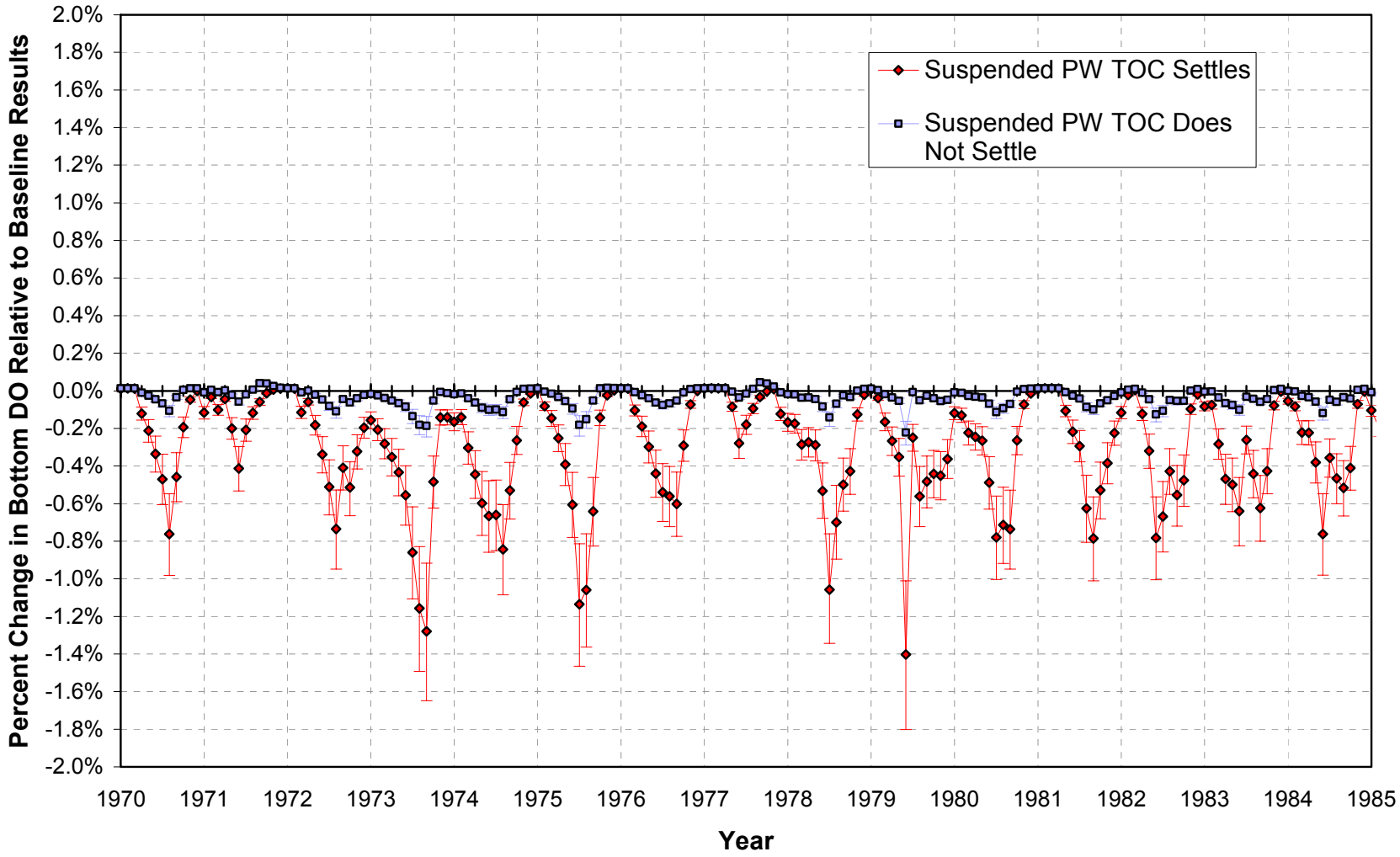
Justić – PW Delivered at Delta



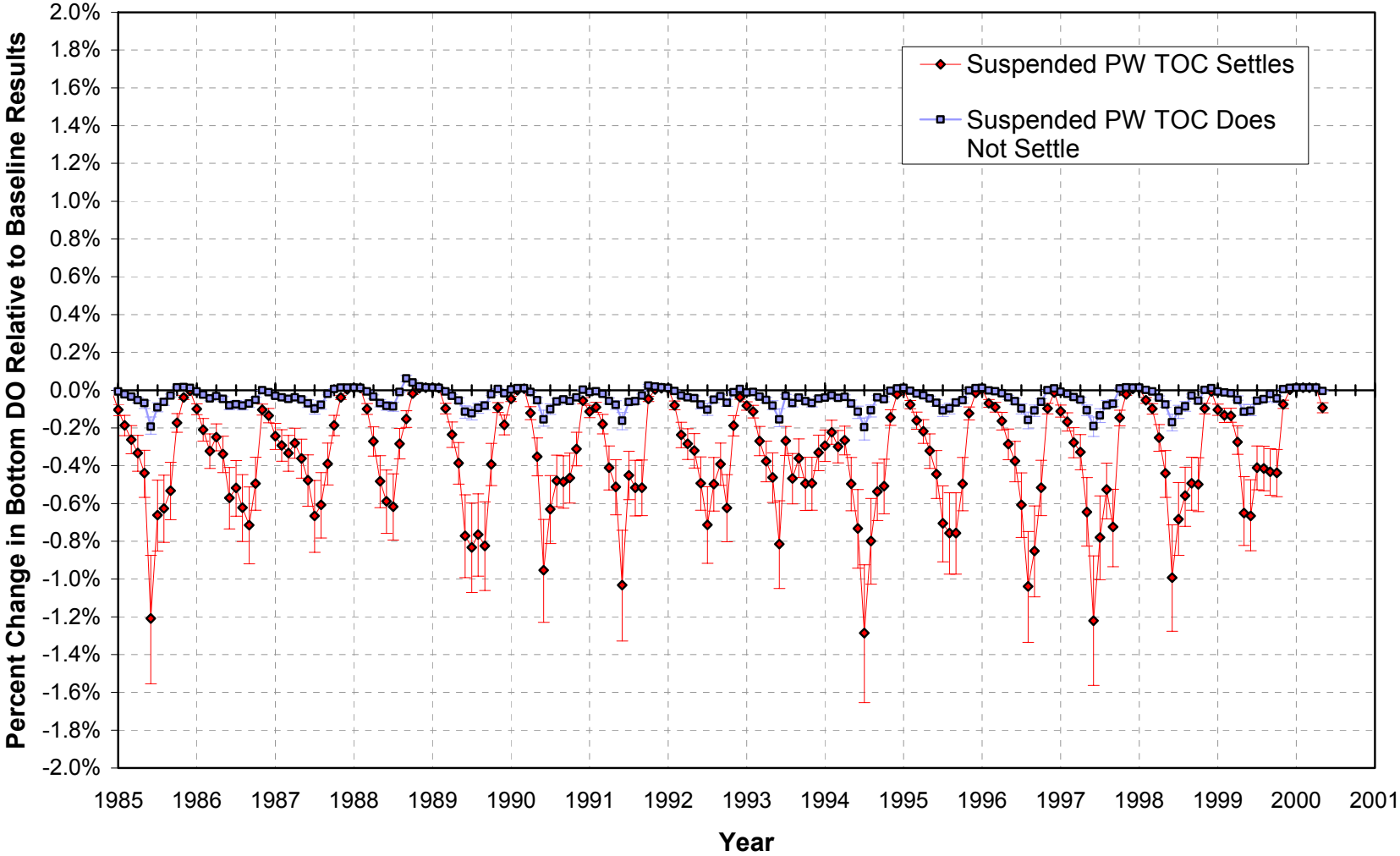
Justić – PW Delivered at C6



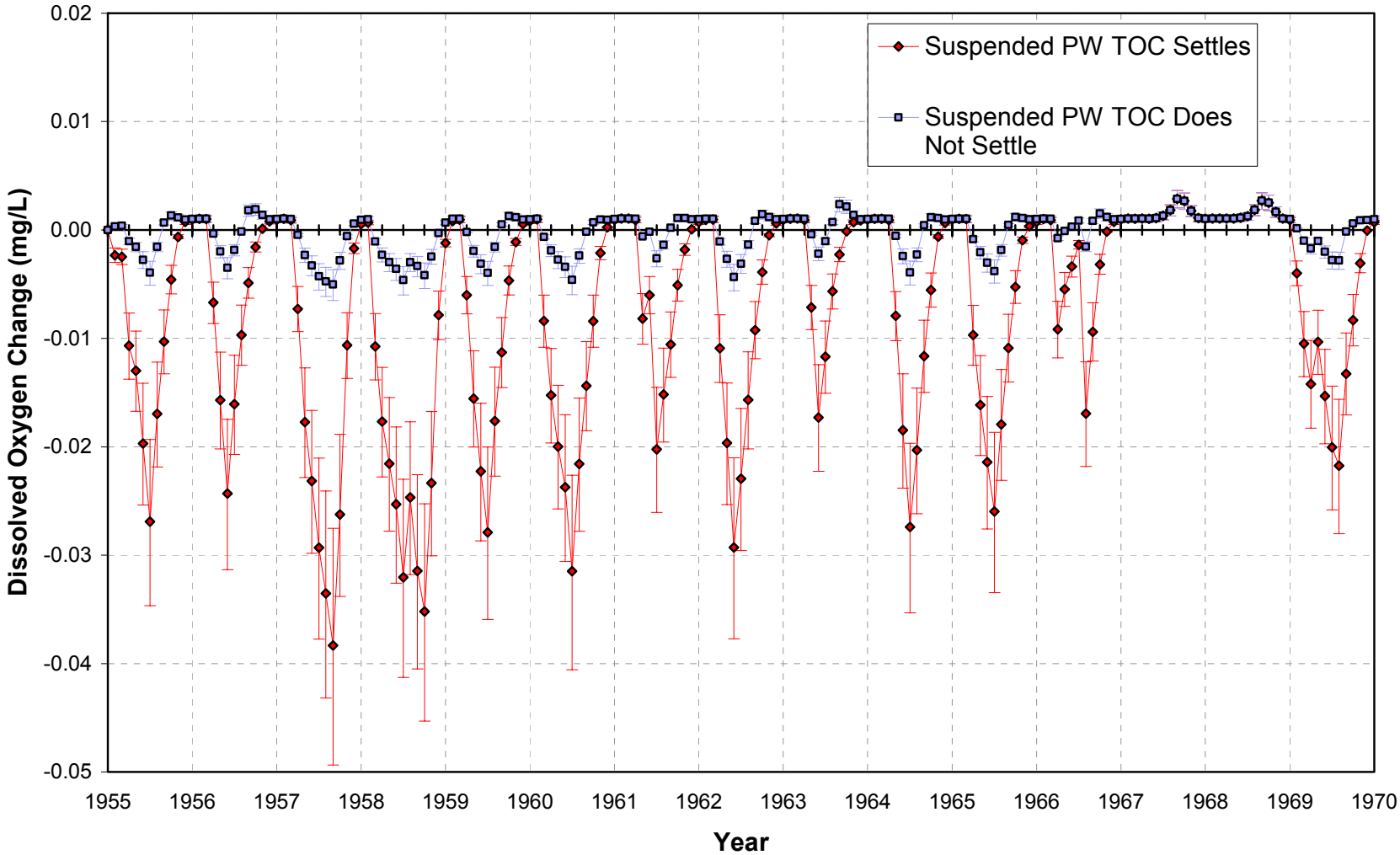
Justić – PW Delivered at C6



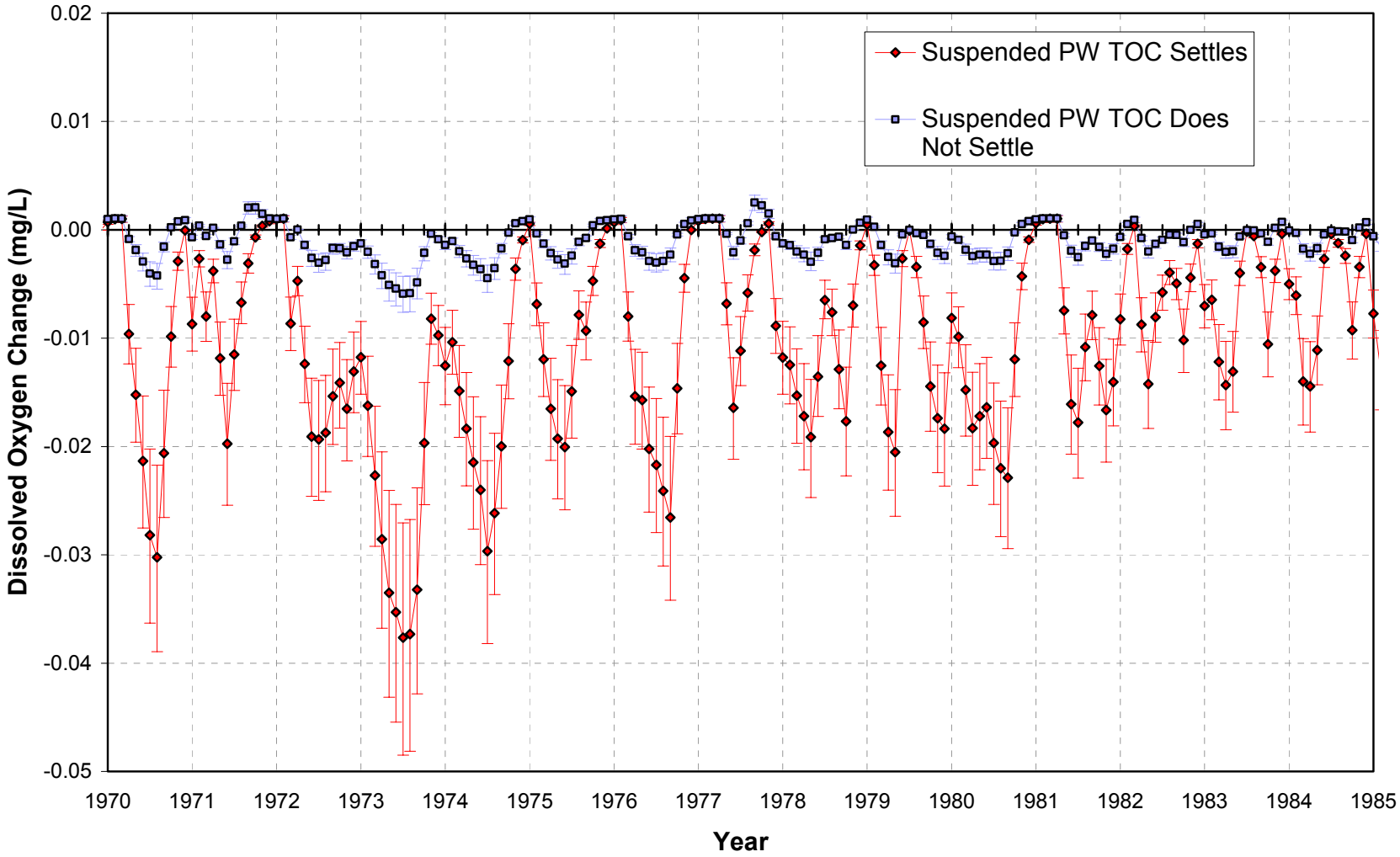
Justić – PW Delivered at C6



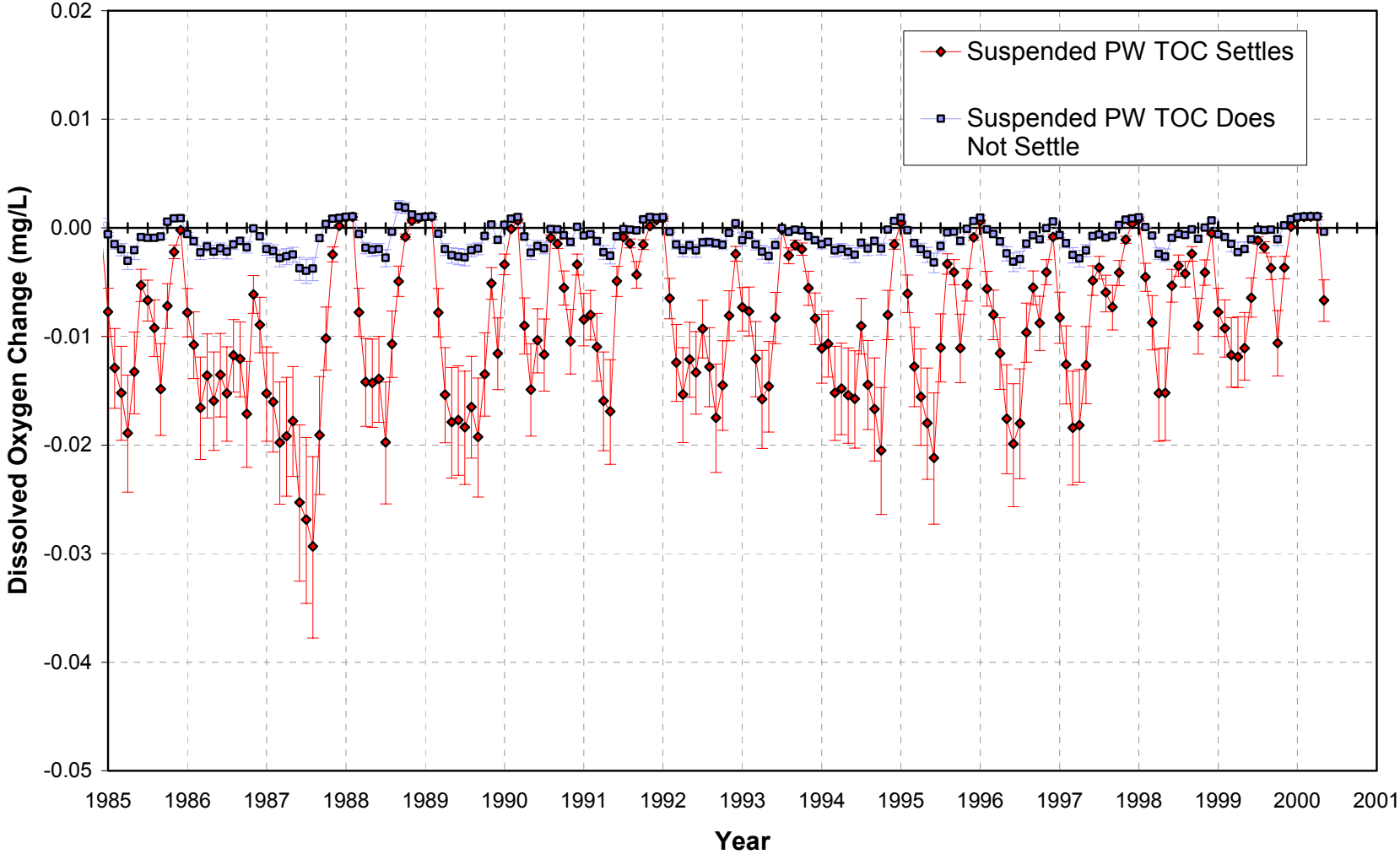
Justić – PW Delivered at C6



Justić – PW Delivered at C6



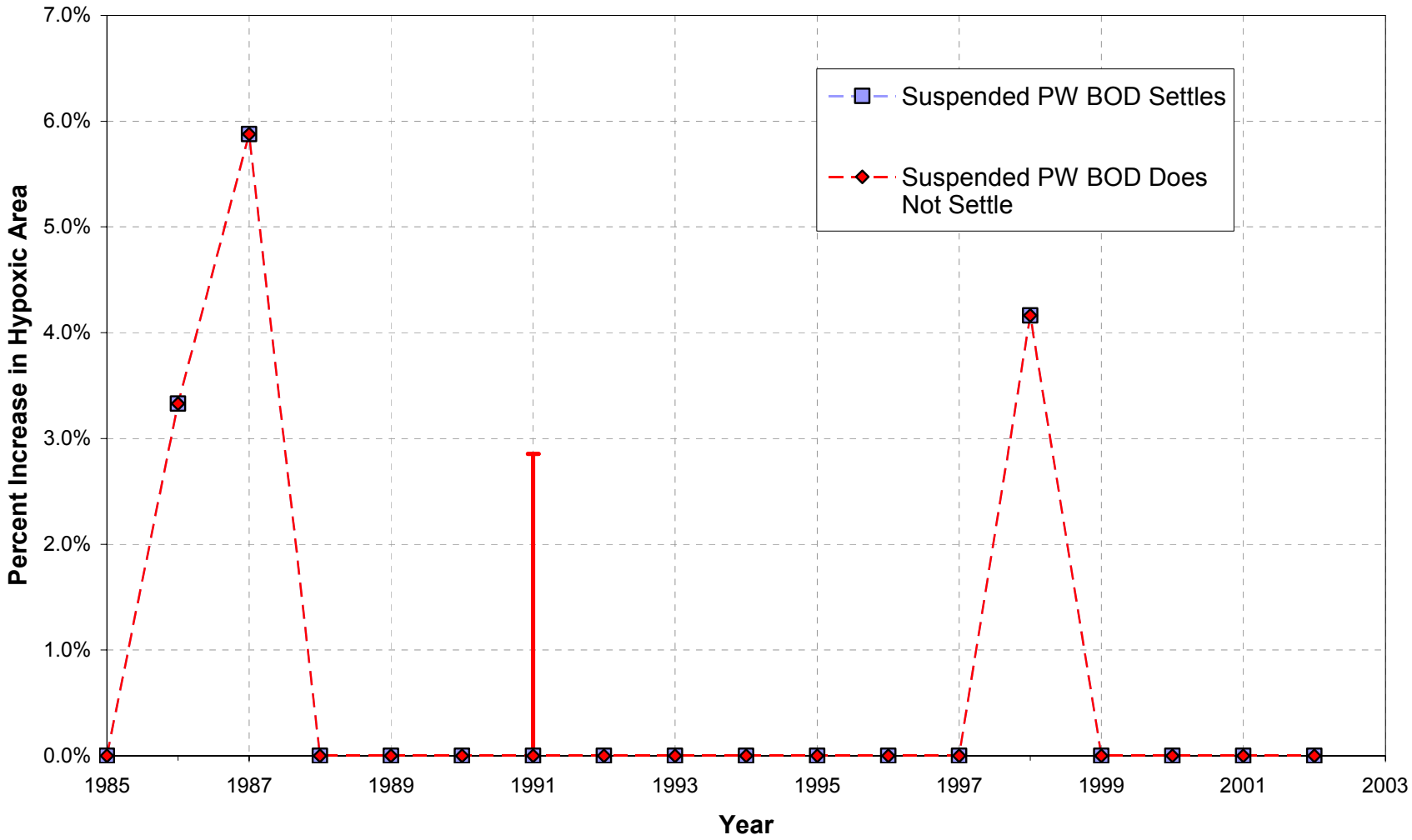
Justić – PW Delivered at C6



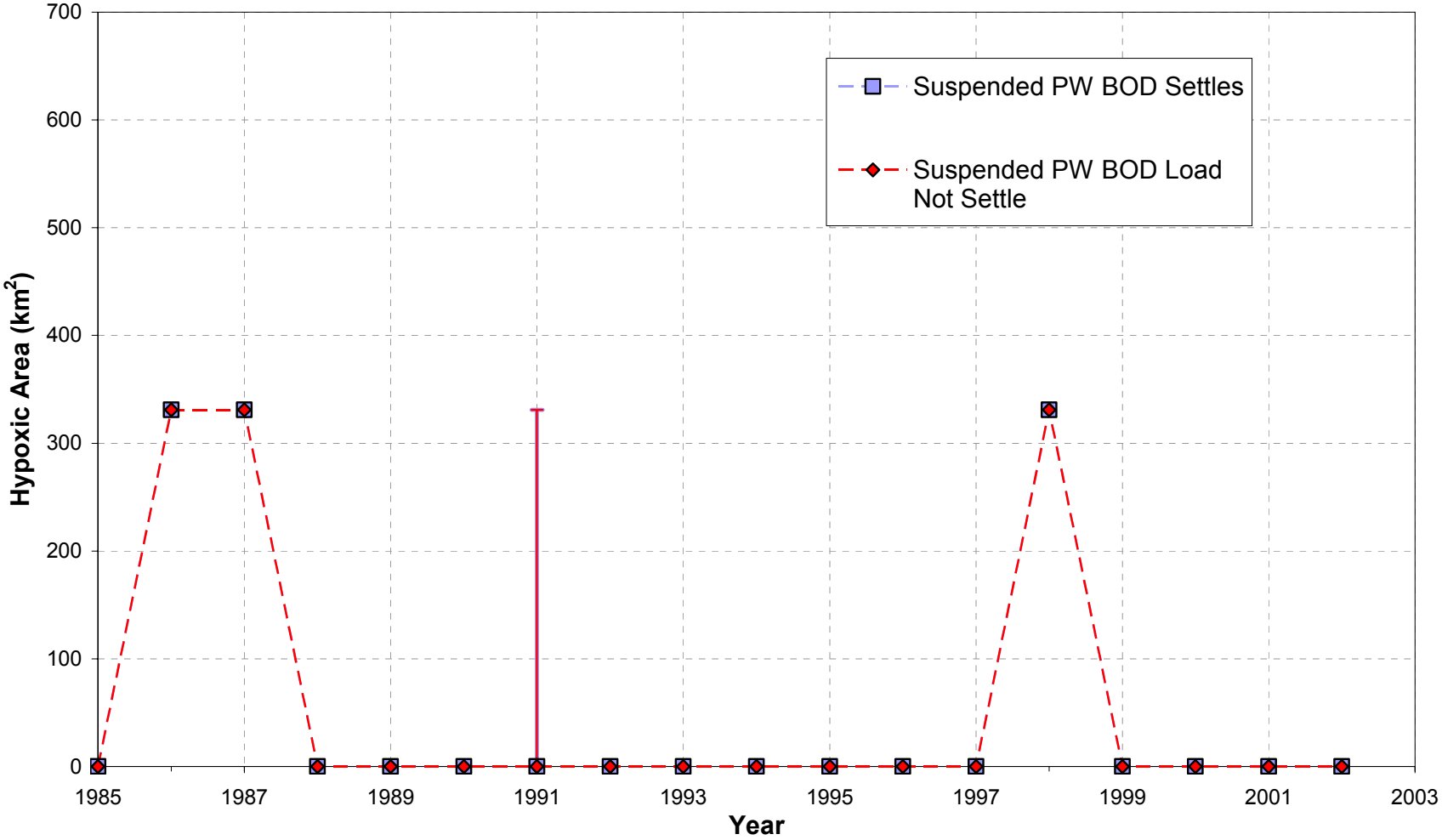
Scavia Model Summary Results

- PW Loads delivered at Mississippi and Atchafalaya Rivers
  - For base PW loads, hypoxic area increased in 3 of 18 years by an average of 4.5%
- PW Loads apportioned along spine of hypoxic zone
  - For base PW, hypoxic area increased in 2 of 18 years by an average of 3.1%

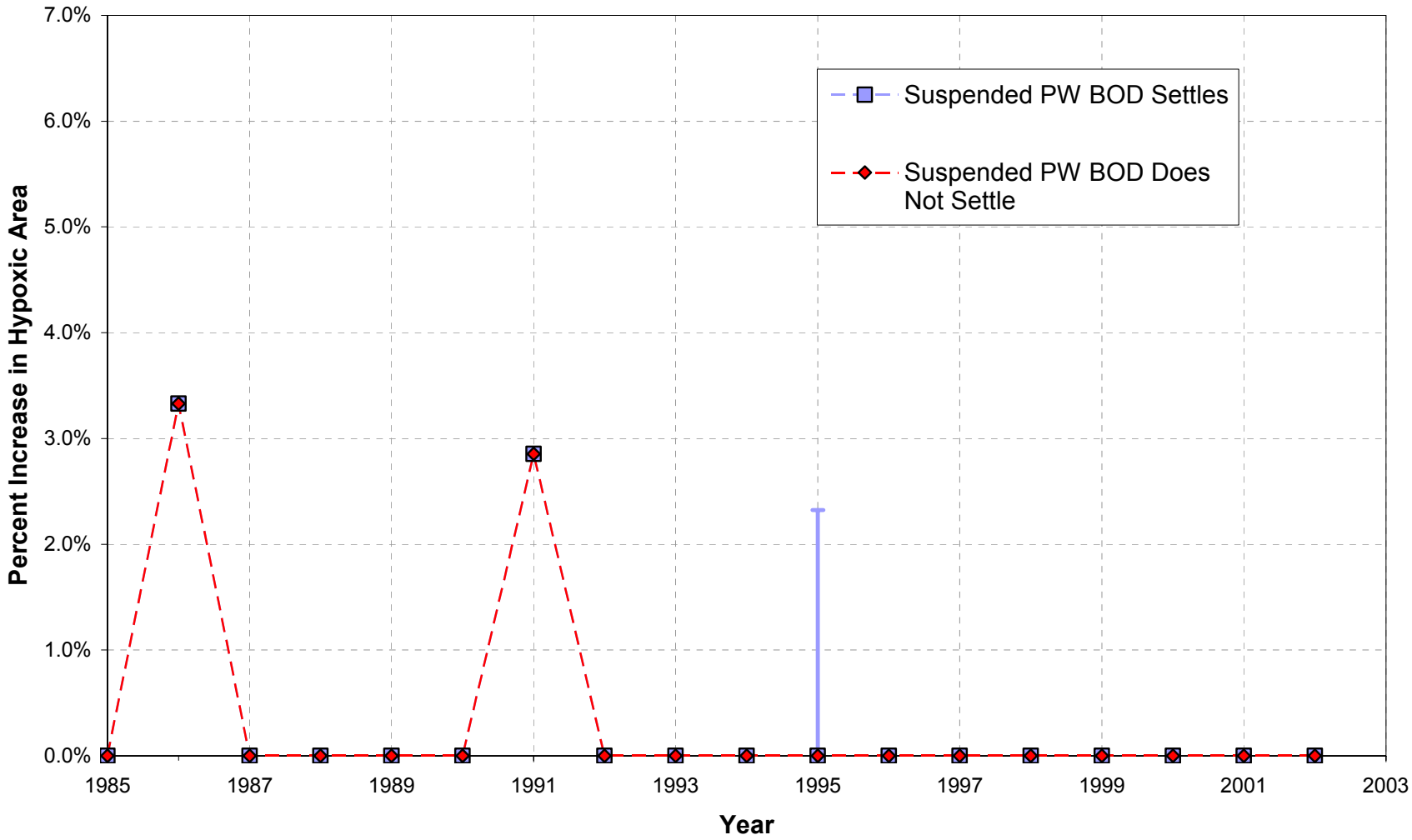
Scavia – PW Delivered at Rivers



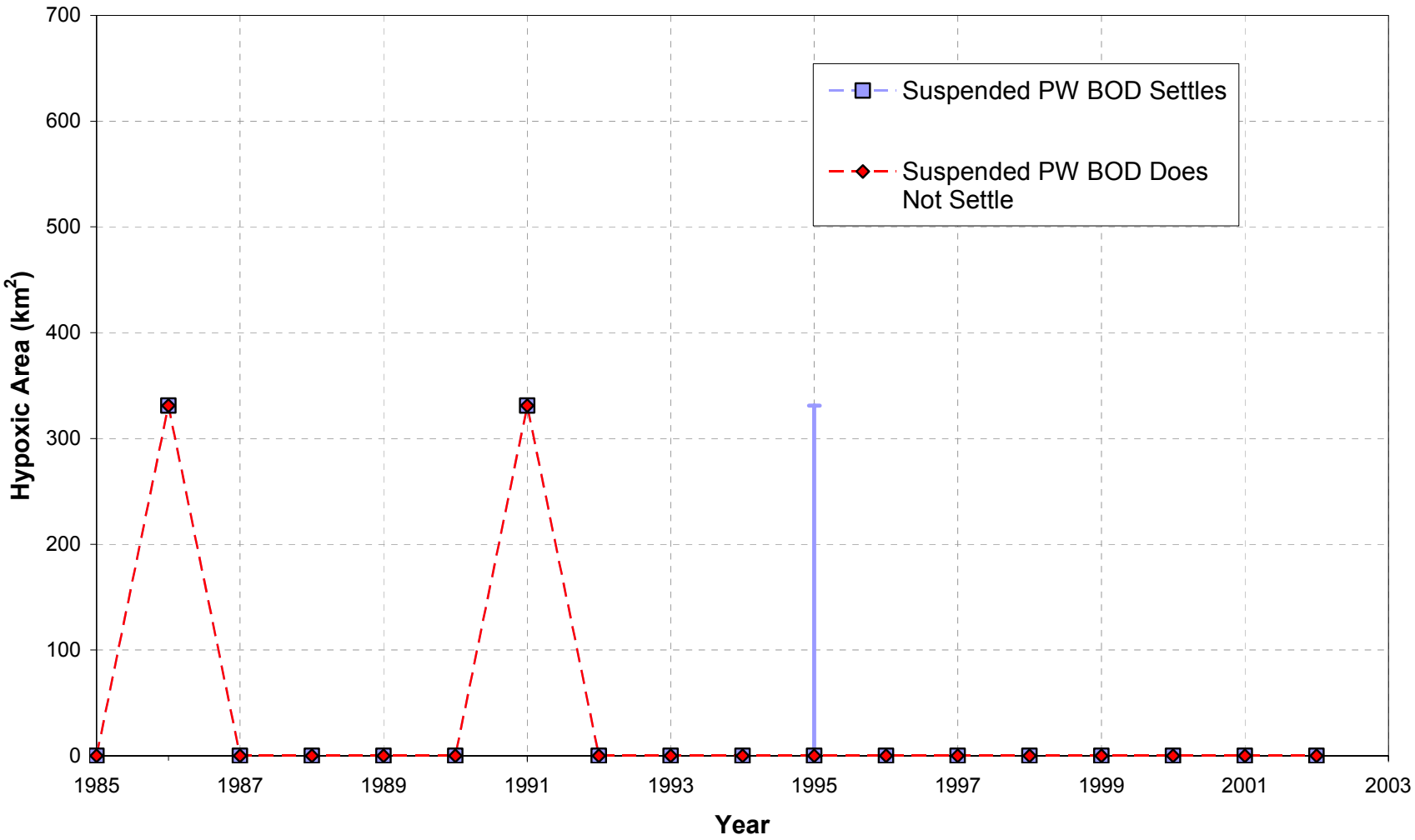
Scavia – PW Delivered at Rivers



Scavia – PW Delivered Along Spine



Scavia – PW Delivered Along Spine



Summary Conclusions

- Predicted incremental impacts of PW loads on dissolved oxygen conditions in the northern Gulf of Mexico from all three models were small.
- The predicted impacts are likely to be within the errors of measurement for bottom water dissolved oxygen and hypoxic area at the spatial scale of the hypoxic zone.

References

Bierman, V.J., Jr., S.C. Hinz, D. Zhu, W.J. Wiseman, Jr., N.N. Rabalais, and R.E. Turner. 1994. A preliminary mass balance model of primary productivity and dissolved oxygen in the Mississippi River plume/inner Gulf Shelf region. Estuaries 17:886–99.

Goolsby, D.A., W.A. Battaglin, G.B. Lawrence, R.S. Artz, B.T. Aulenbach, R.P. Hooper, D.R. Keeney, and G.J. Stensland. 1999. Flux and sources of nutrients in the Mississippi-Atchafalaya River Basin: Topic 3 report for the integrated assessment on hypoxia in the Gulf of Mexico. NOAA Coastal Ocean Program Decision Analysis Series No. 17. NOAA Coastal Ocean Program, Silver Spring, MD. 130 pp.

Justić, D., N.N. Rabalais, and R. E. Turner. 1996. Effects of climate change on hypoxia in coastal waters: A doubled CO2 scenario for the northern Gulf of Mexico. Limnol. Oceanogr. 41:992–1003.

Rabalais, N.N, R.E. Turner, and D. Scavia. 2002. Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi River. BioScience 52:129–142.

References (cont.)

Scavia, D., N.N. Rabalais, R.E. Turner, D. Justić, and W.J. Wiseman, Jr. 2003. Predicting the response of Gulf of Mexico hypoxia to variations in Mississippi River nitrogen load. Limnol. Oceanogr. 48:951–956.

Smith, J.P. ExxonMobil Upstream Research Company, personal communication.

Veil, J.A., T.A. Kimmell, and A.C. Rechner. 2005. Characteristics of produced water discharged to the Gulf of Mexico hypoxic zone. ANL/EAD/05-03. Prepared for U.S. Department of Energy, National Energy Technology Laboratory, August.