Total Maximum Daily Load for Dioxin in the Houston Ship Channel

University of Houston
Parsons Water&Infrastructure

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Focus

- RMA2-WASP modeling update
- Load allocation spreadsheet model

RMA2-WASP modeling update

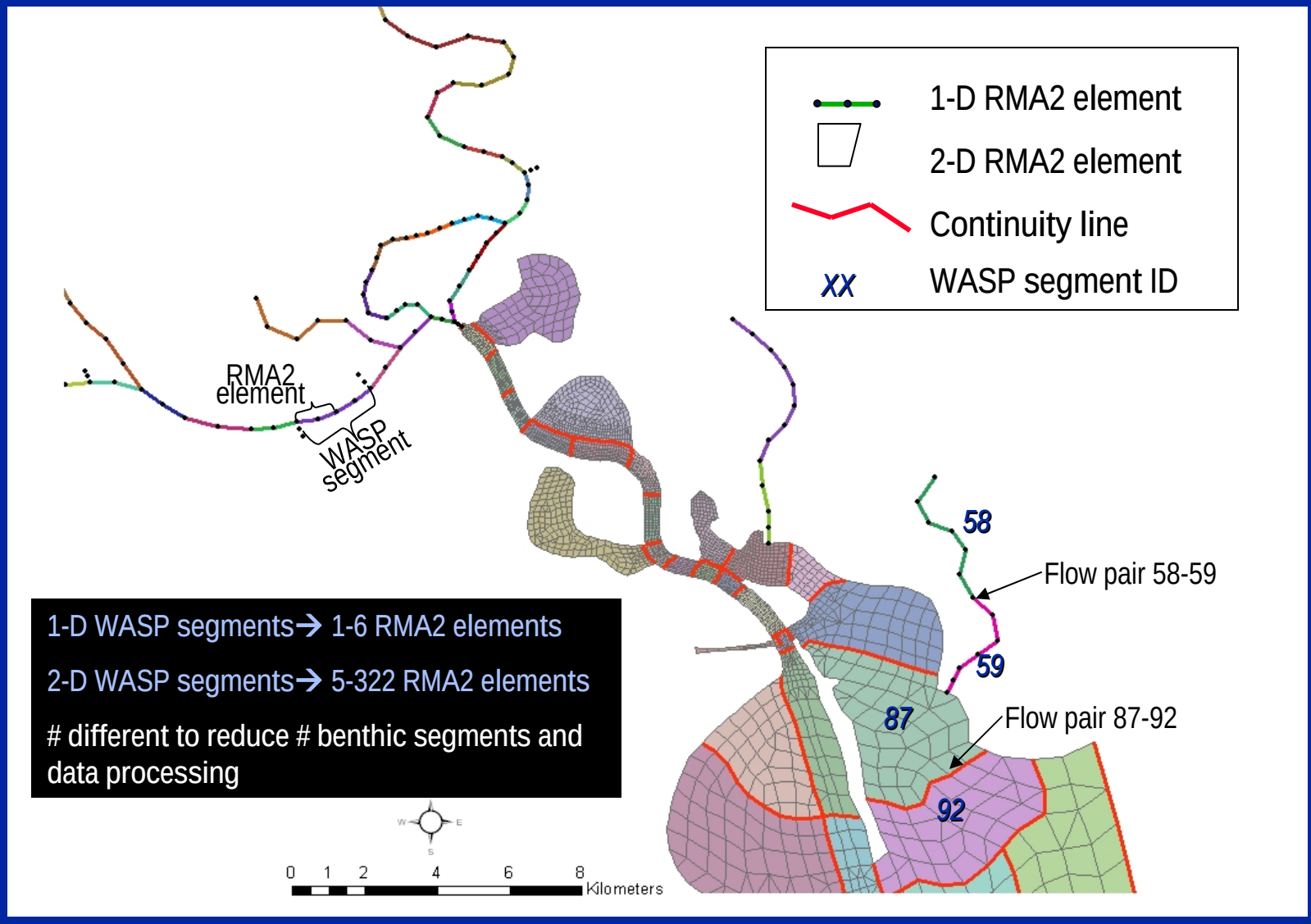
It all started with Larry's comments:

"What got me on this was the "average flow" of 42.8 cms out of Burnett Bay - that's a LOT of water, there is no river into the bay…"

and

"[You] could crosscheck volume calculations by comparing different calculations."

RMA2-WASP segmentation



RMA2-WASP modeling process

RMA2 Geometry File
Node coordinates, bottom elevations, nodes comprising each element

RMA2 Output
Depth, Vx, Vy, flow for 1-D nodes
Depth, Vx,Vy for 2-D nodes
Flows across "continuity lines"

Junction File
Flow pairs (1-D and 2-D elements)
RMA2 elements composing each WASP segment

Interface (HSCREAD)

Calculates average depth for each WASP segment on a time-step basis

Calculates volume for each WASP element for each time step by aggregating volumes of RMA elements (1-D: average cross-section*length, 2-D: surface area (also calculated by interface)*depth)

Calculates average velocities at each segment as the resultant of all the velocity vectors

Calculates flows in and out of a 1-D WASP segment as cross-section area*velocity

Reads flows across a continuity line from RMA output and assign them to the WASP 2-D pairs

Creates a hydrodynamic file in a format that can be read by WASP

WASP
Uses volume data to calculate concentrations and flows to move contaminant between segments.
Velocities used for re-aeration rates (not applicable to dioxin modeling)

Hydrodynamic model issues

- Net flow out of side bays too high
- Mass-balance not preserved for individual RMA2 elements (model checks balance for the entire system only). RMA2 calculates water surface elevations on a node-basis using continuity equation and velocities using conservation of momentum
- Model output flows for continuity lines with only 2 nodes inaccurate
- Wetting/drying of upstream reaches caused model to crash (long-term run)
- There were water losses between some 1-D elements

Mass-balance issue

For a given WASP element it should be true that

$$V_{t+1} = V_t + (Q_{in_t} - Q_{out_t}) \cdot dt$$

and

$$V_{t+1} = \overline{A}_{x\,\mathrm{sec}\,t+1} \cdot length$$

The RMA2 Manual recommends that the difference between change in storage and change in volume not be greater than 3% for a given time step, otherwise there could be problems in the water quality simulation

How were the issues addressed?

- 1-D element geometry at some junctions was modified to eliminate water leaks
- Upstream reaches with bottom elevations higher than -0.5 m above sea level were eliminated
- 2-D grid was refined to minimize mass-balance problems
- Continuity lines were specified so that at least two RMA2 elements were on each side of the interface (5 nodes)

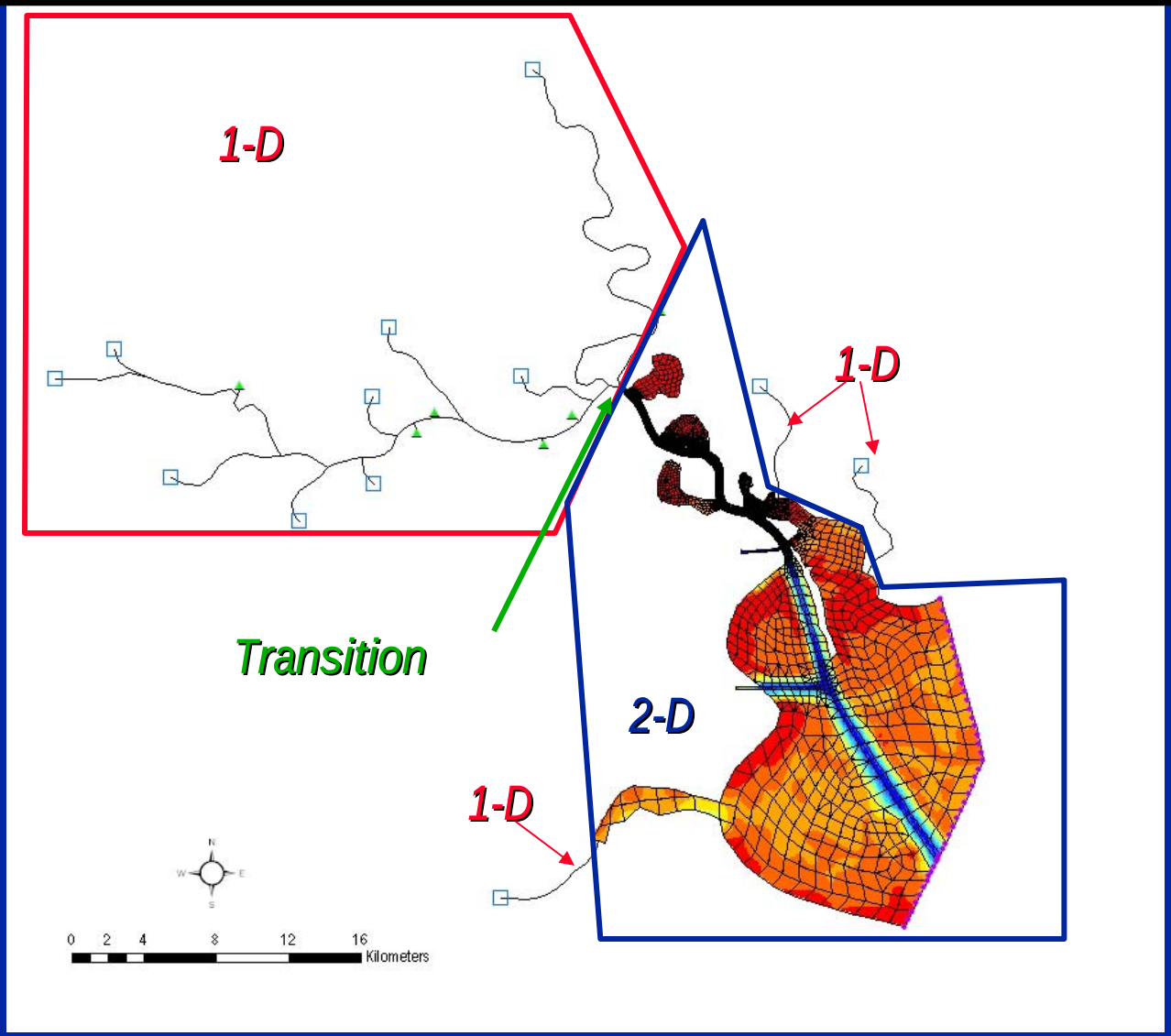
RMA2 mesh refinement

- The RMA2 model segmentation was refined so that for each of the WASP segments, the difference in volumes calculated using the two different methods was not greater than 3% of the volume at any time step.
- Iterative process.
- There are still a few WASP segments that have errors greater than the criterion for a number of time steps.

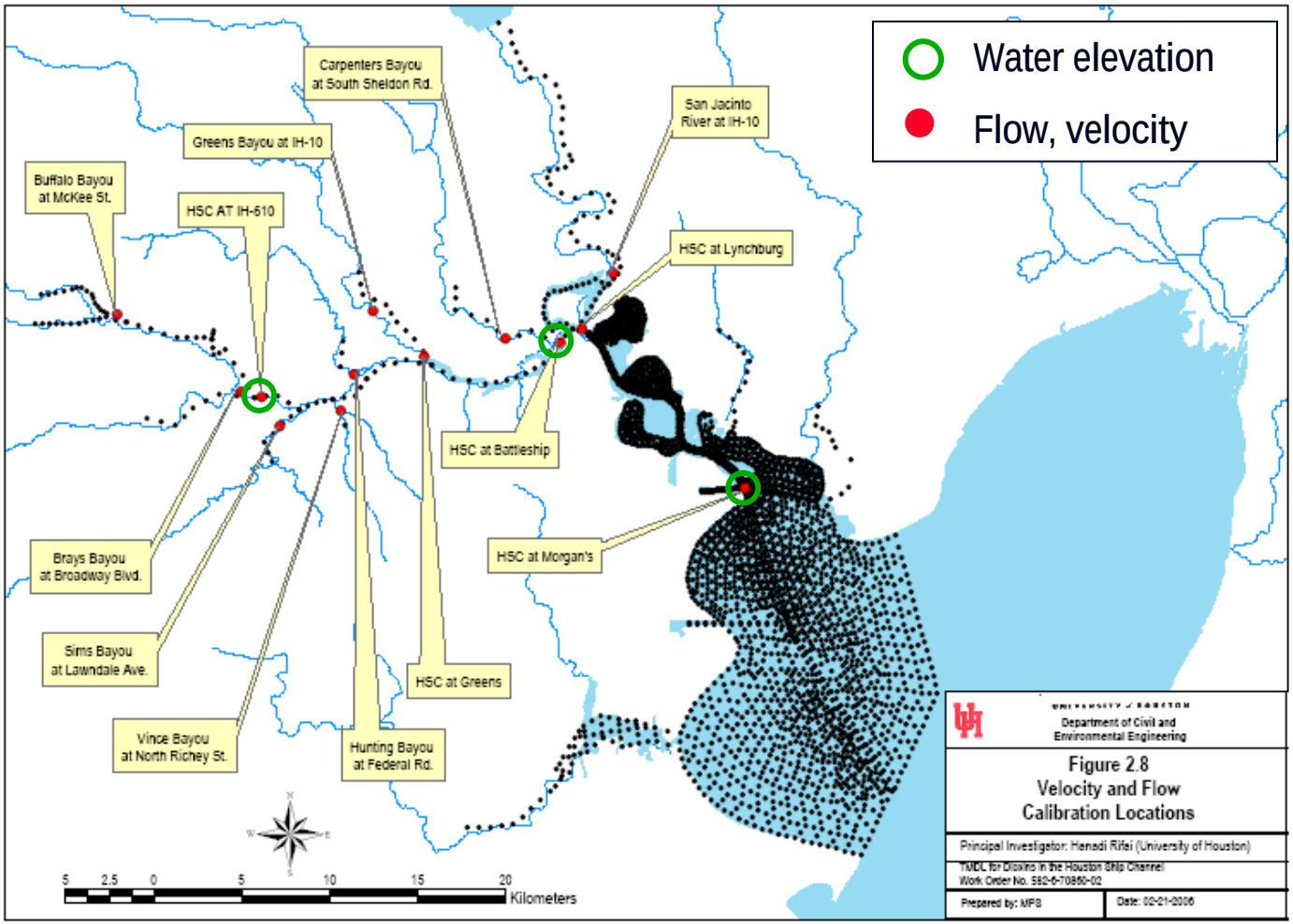
RMA2 model for the HSC and UGB

- 108 linear elements (including major tributaries), 3228 2-D elements, 16 junction elements, 4 transition elements
- Calibration period: March 20 to April 21, 2005
- Time step: 6 minutes
- Spin-up time: 48 hours (480 time steps)
- Boundaries
  - *d/s: tide data from NOAA*
  - *u/s freshwater inflows from major tributaries (USGS hourly data) plus point source self-reported flows (includes runoff)*
  - *inflows from PS discharging to the channel (@ five locations)*
- Meteorology: wind, rainfall, and evaporation data

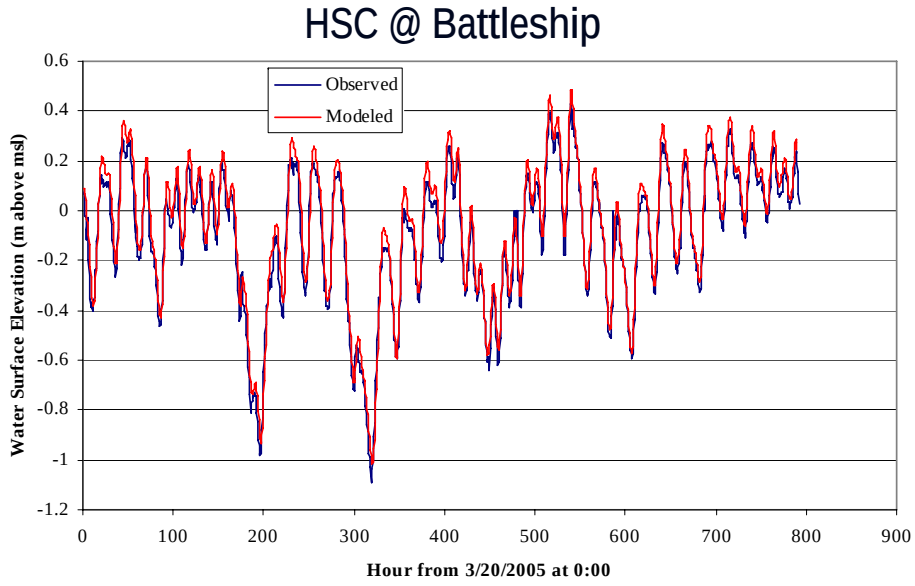
RMA2 current model segmentation

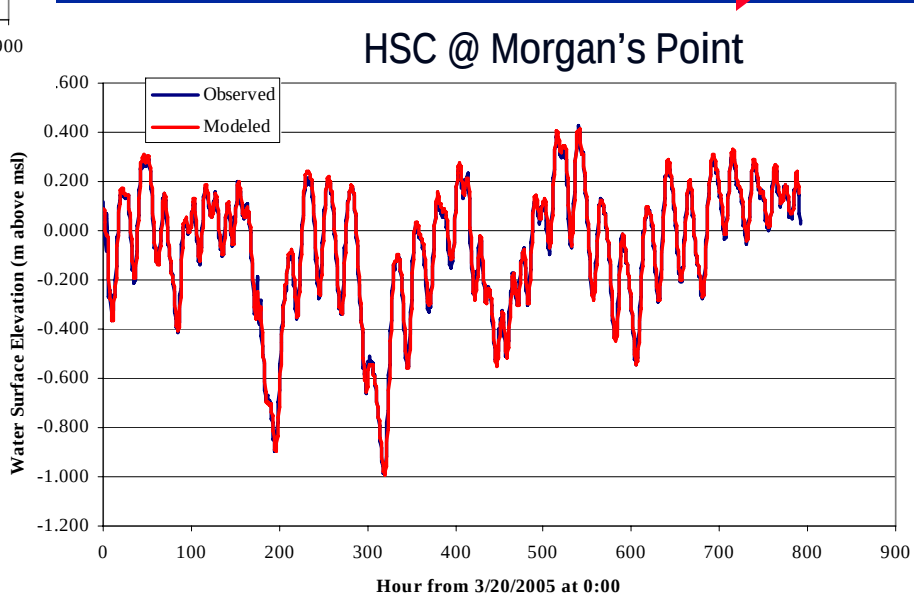


RMA2 model – calibration locations

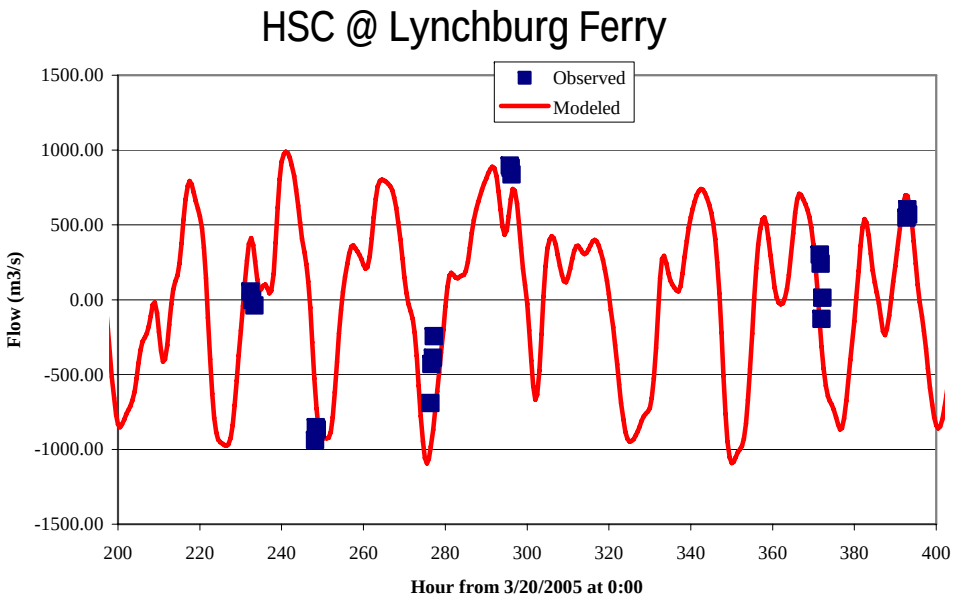


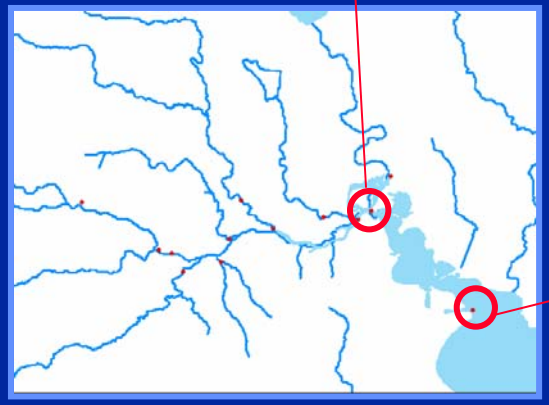
RMA2 model – WSE calibration

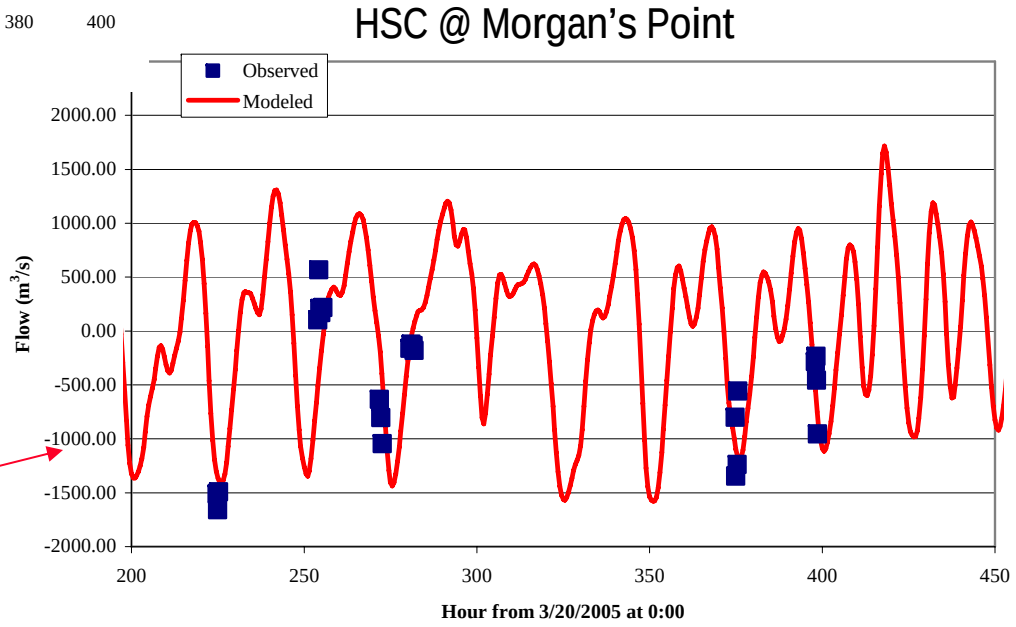




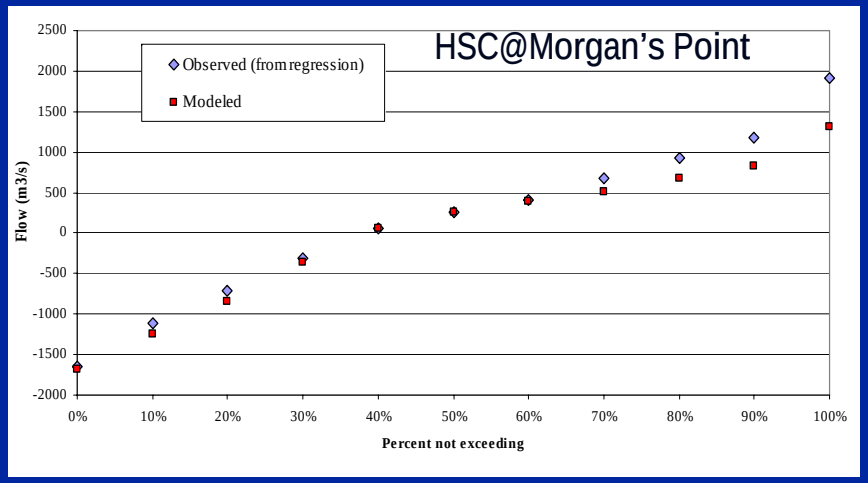
RMA2 model – Flow calibration

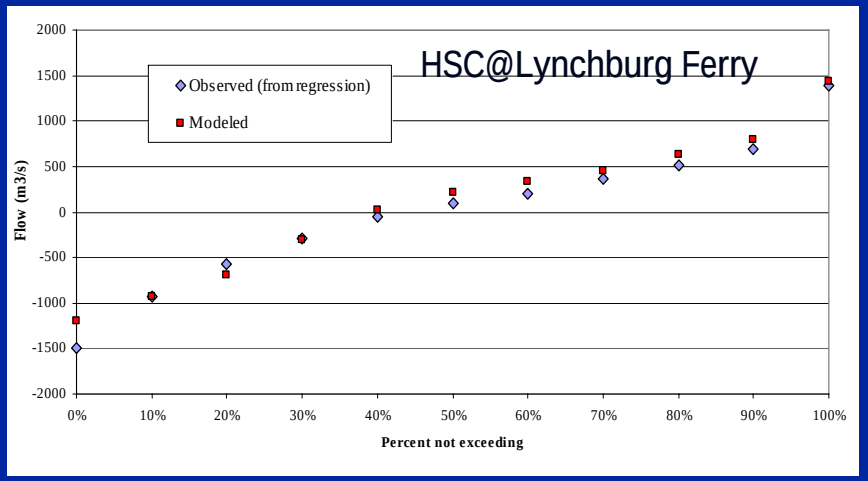


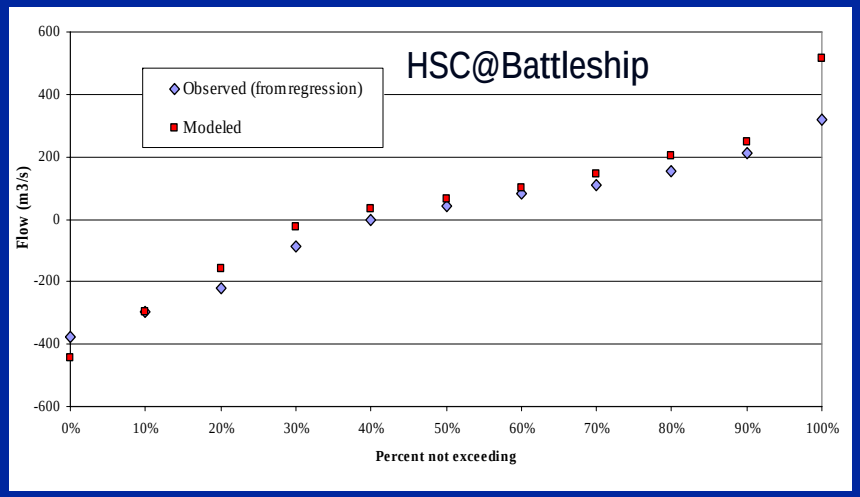


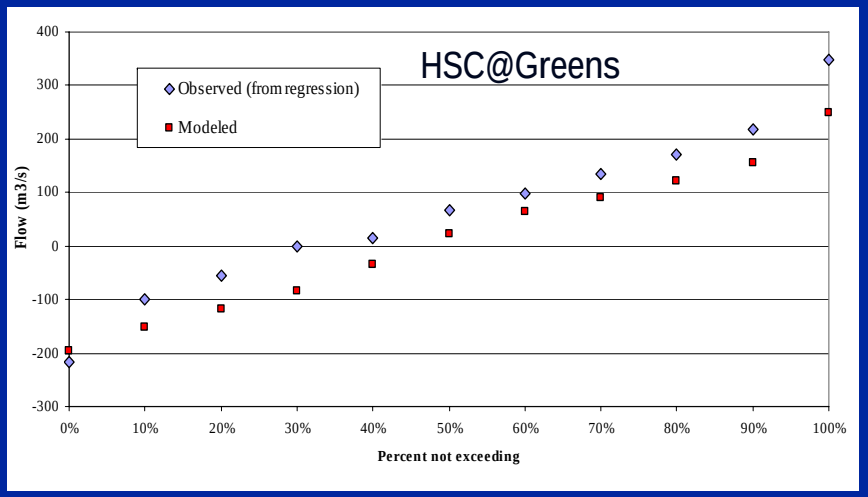


RMA2 model – goodness-of-fit for flow





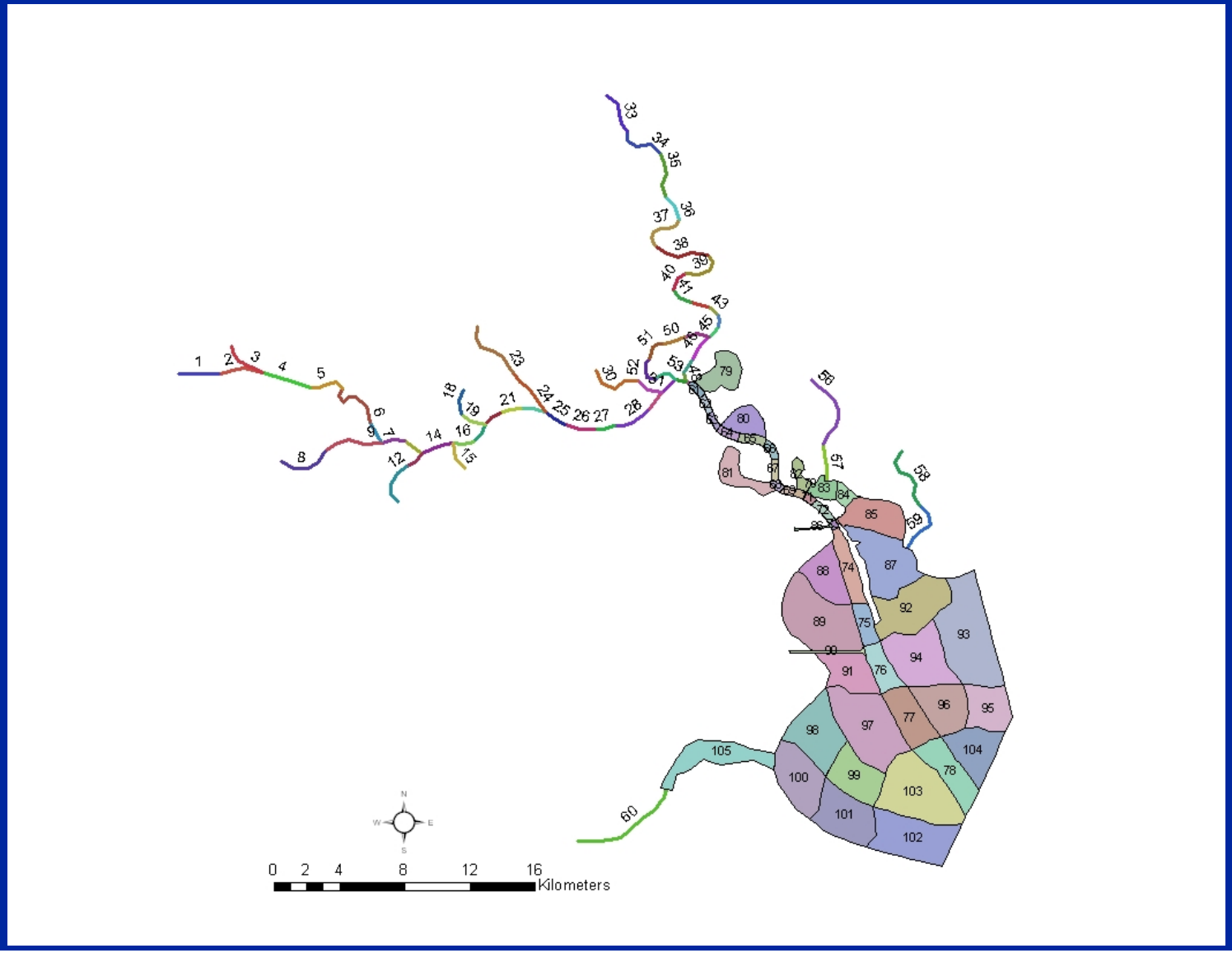




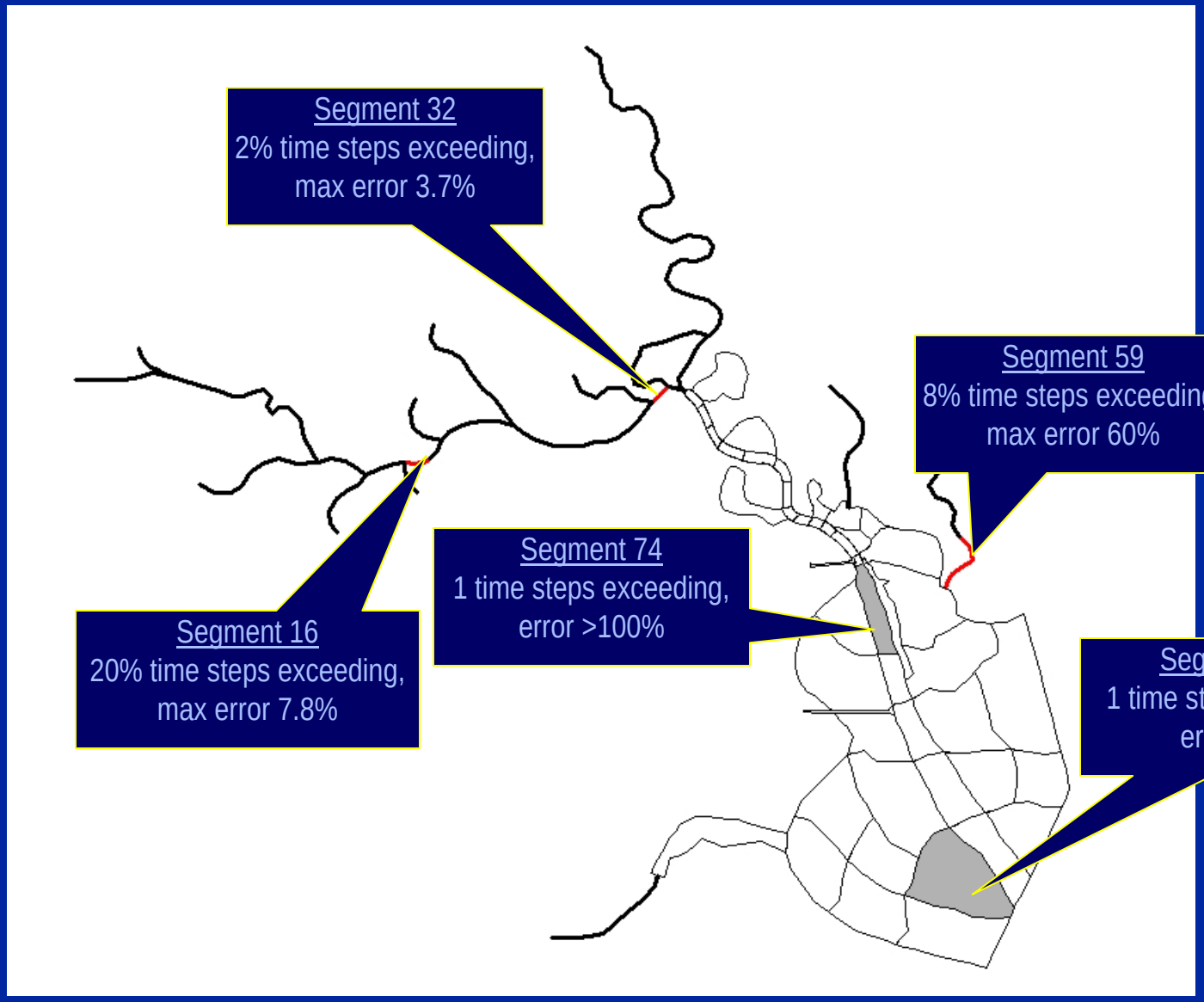
WASP salinity model for HSC and UGB

- 60 1-D water surface elements, 45 2-D water surface elements, 105 benthic elements
- Calibration period for salinity: March 20 to April 21, 2005
- Time step: 6 minutes
- Boundaries
  - *d/s: salinity data for Eagle Point (TCOON)*
  - *u/s: average salinity concentration for major tributaries from historical TRACS data*

WASP current model segmentation

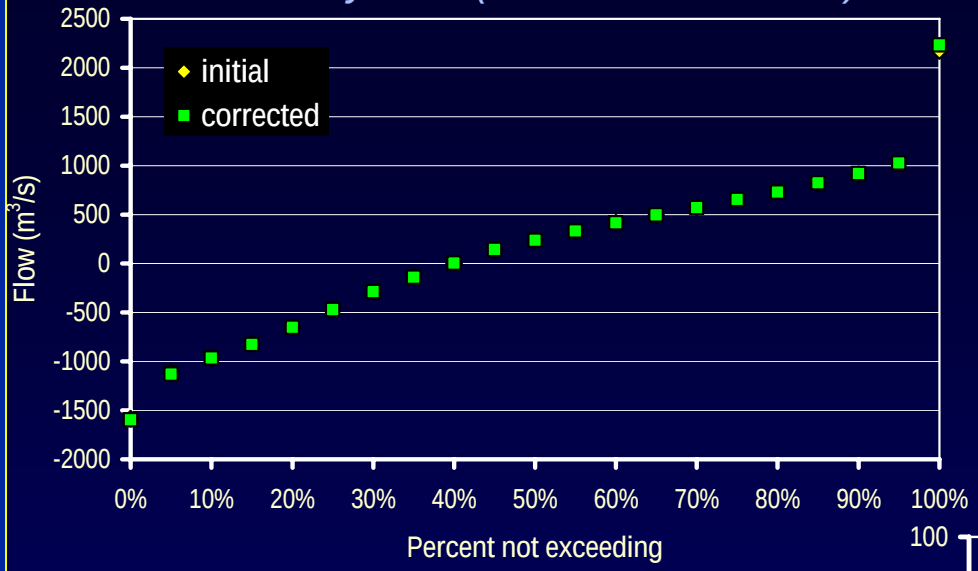


WASP elements with remaining issues

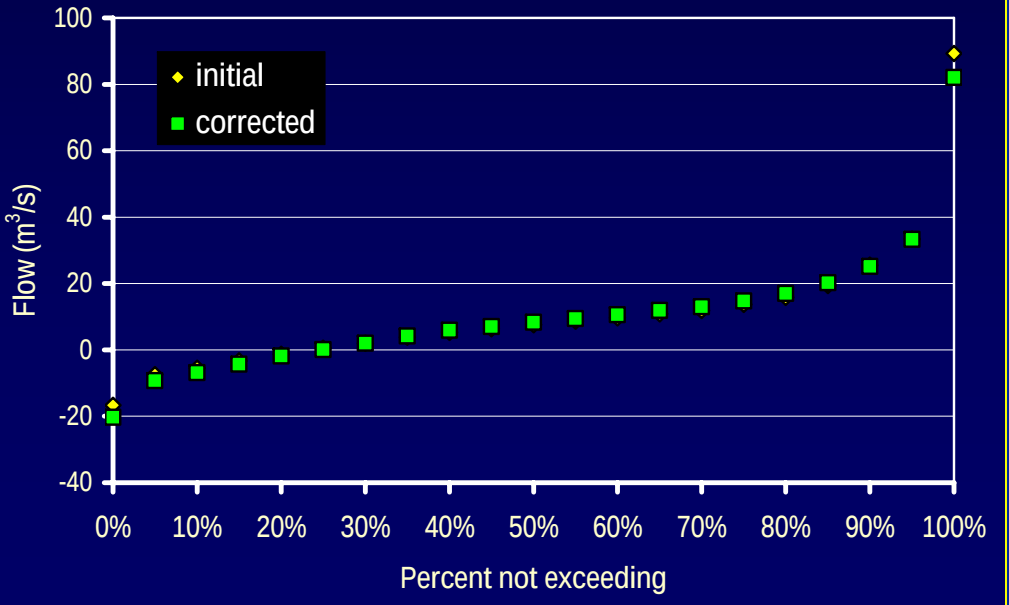


Flow adjustment

Continuity line 6 (WASP 65-66 interface)



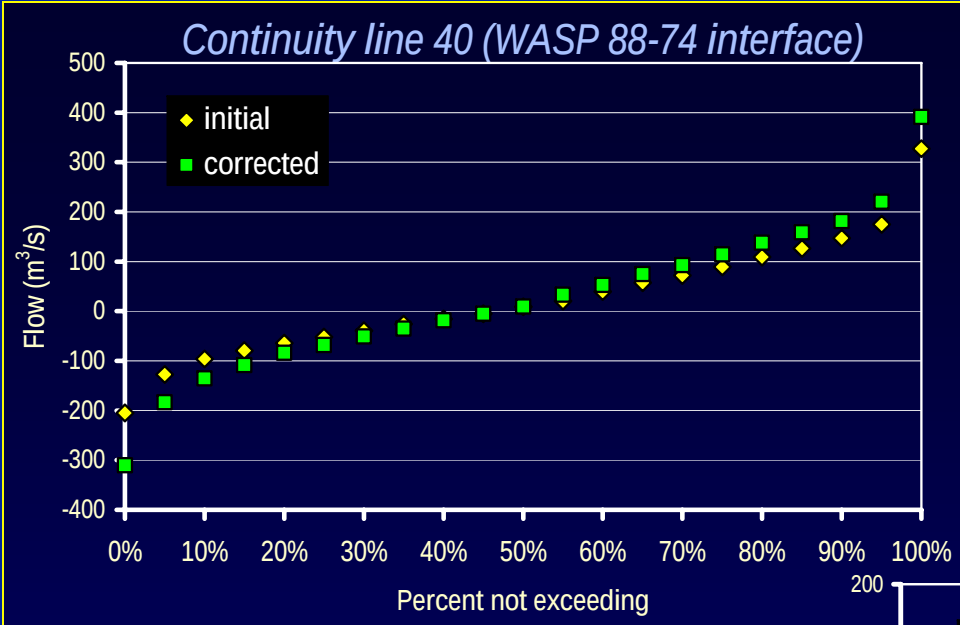
WASP 5-6 interface

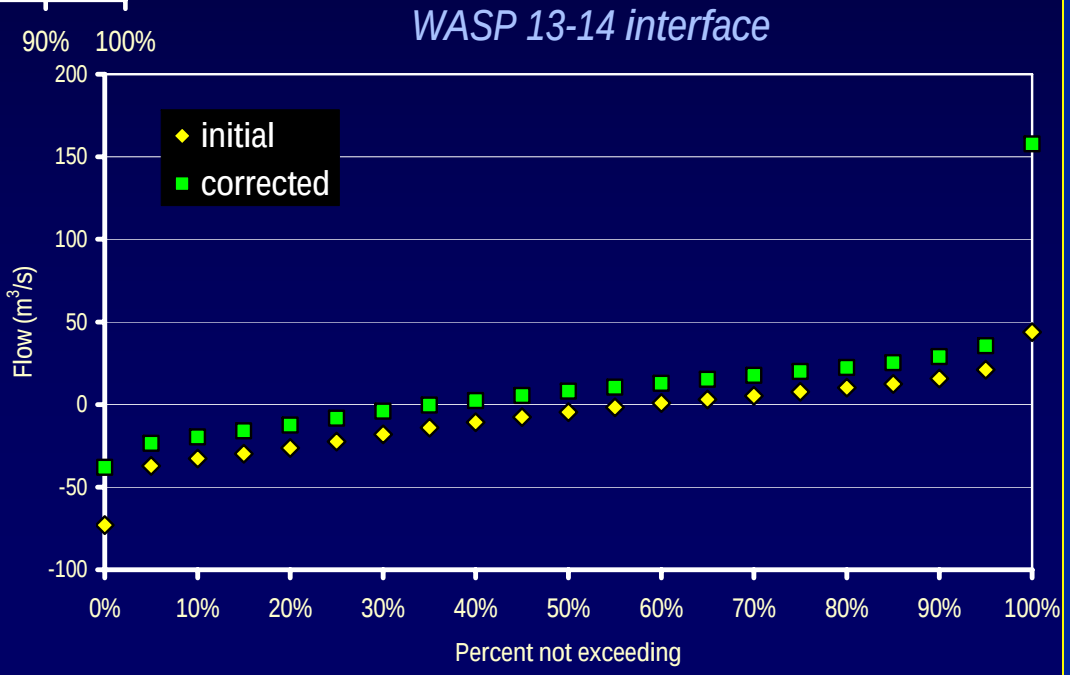


Goal: maintain mass-balance, while preserving flow duration curves

$$Q_{out} = Q_{in} - \frac{\Delta Vol}{dt}$$

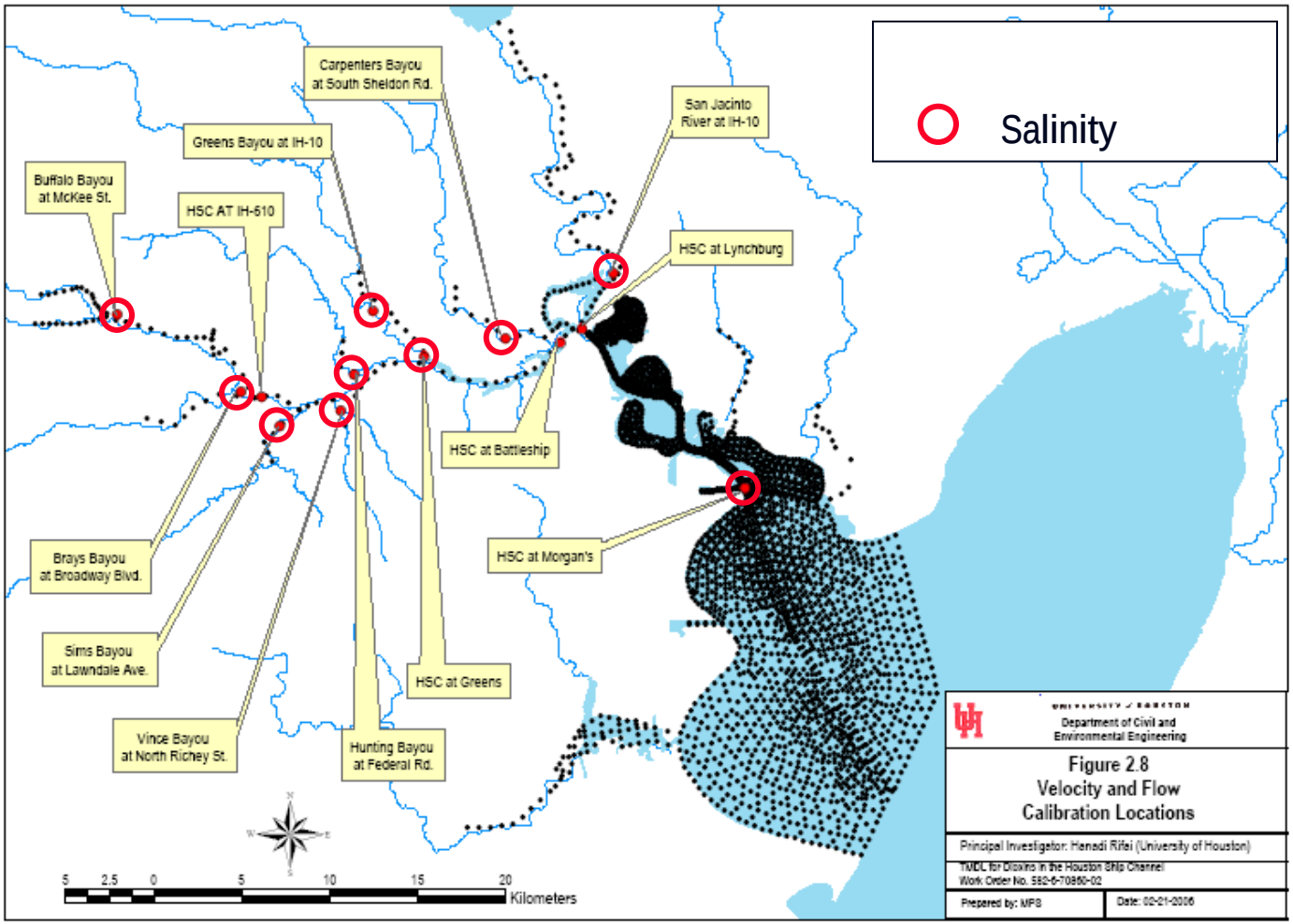
Flow adjustment – cont'd



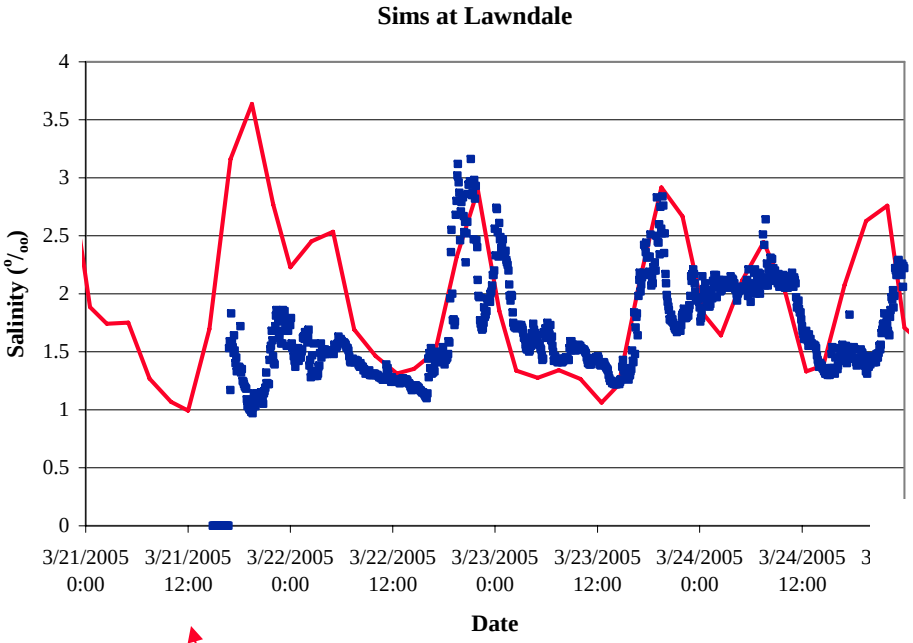


Adjusted outflow for 6% of the interfaces (8 out of 142 flow pairs) did not preserve flow duration curves

Salinity model – calibration locations

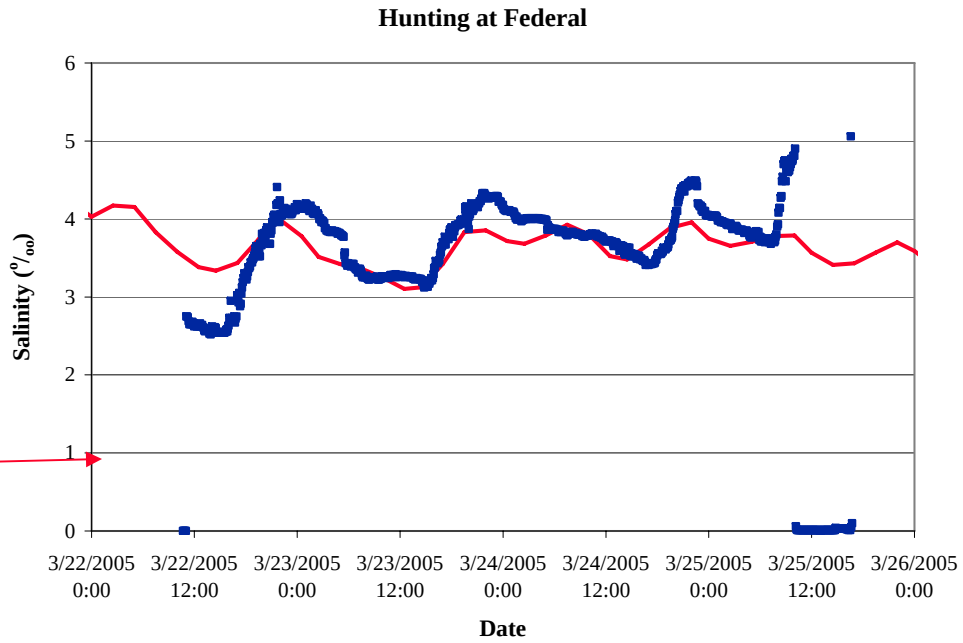


WASP model – salinity calibration

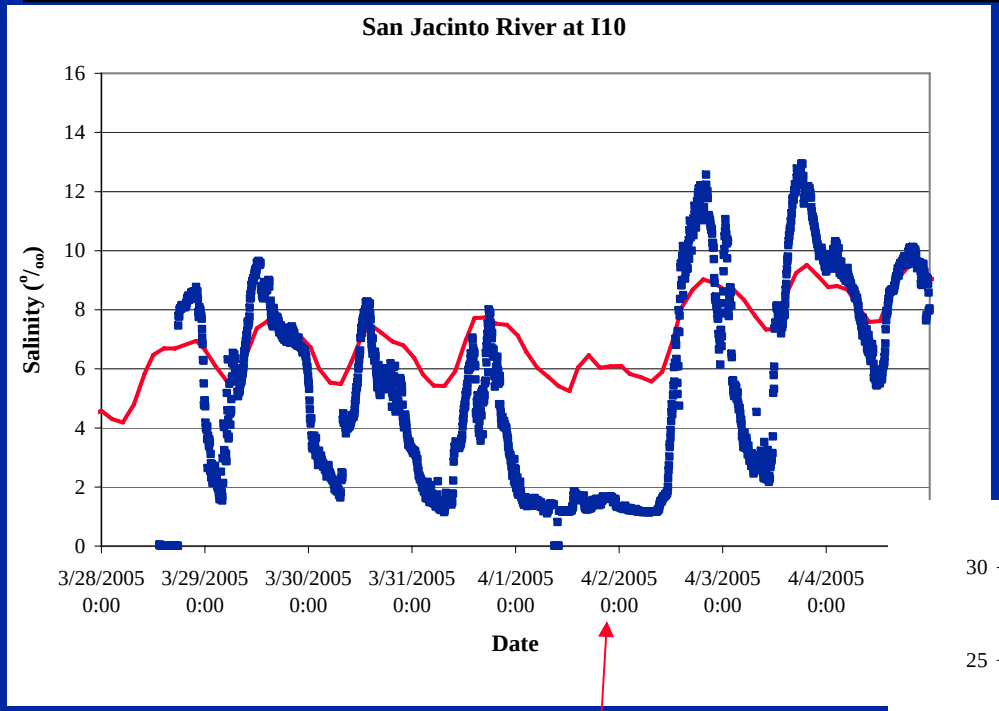


Red → Modeled

Blue → Observed

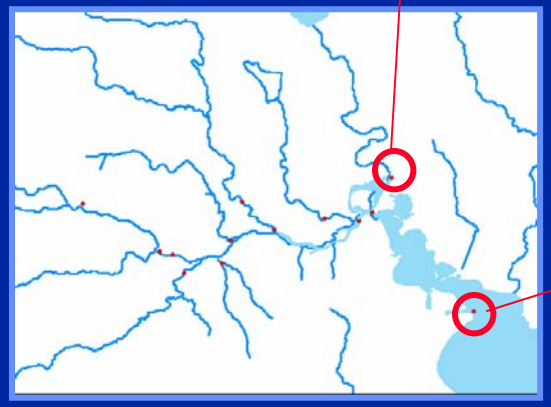


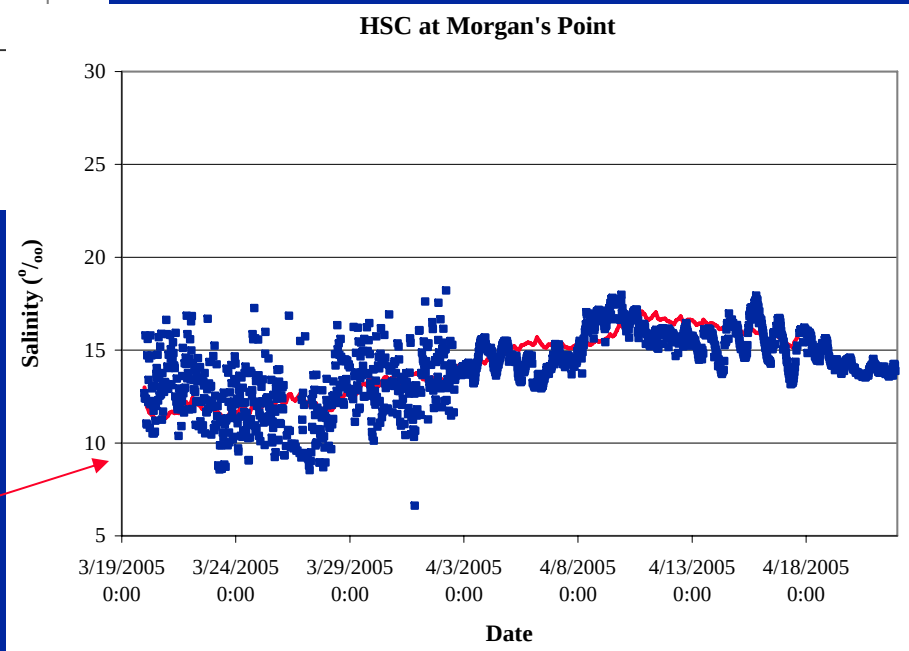
WASP model – salinity calibration (cont'd)



Red → Modeled

Blue → Observed

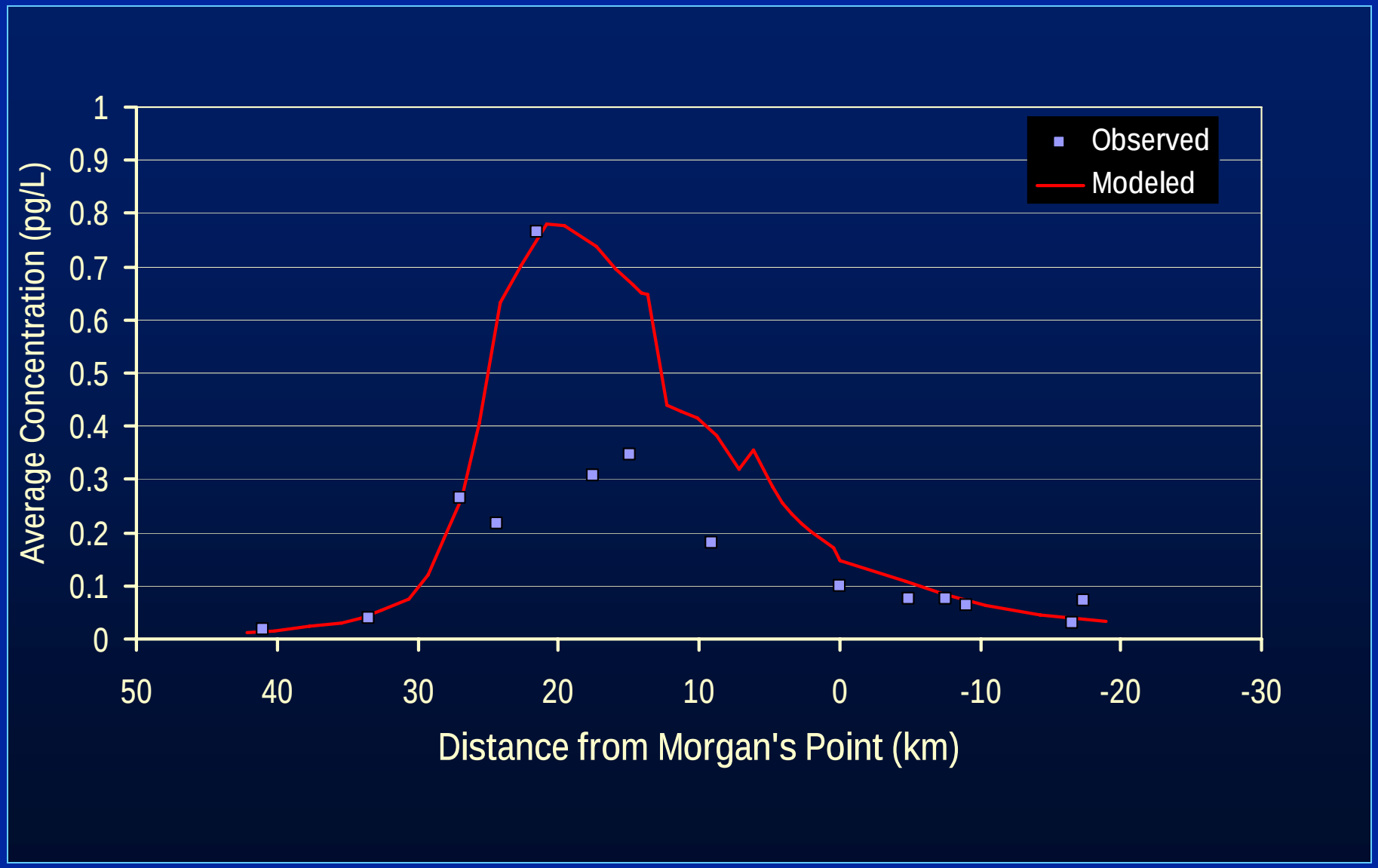




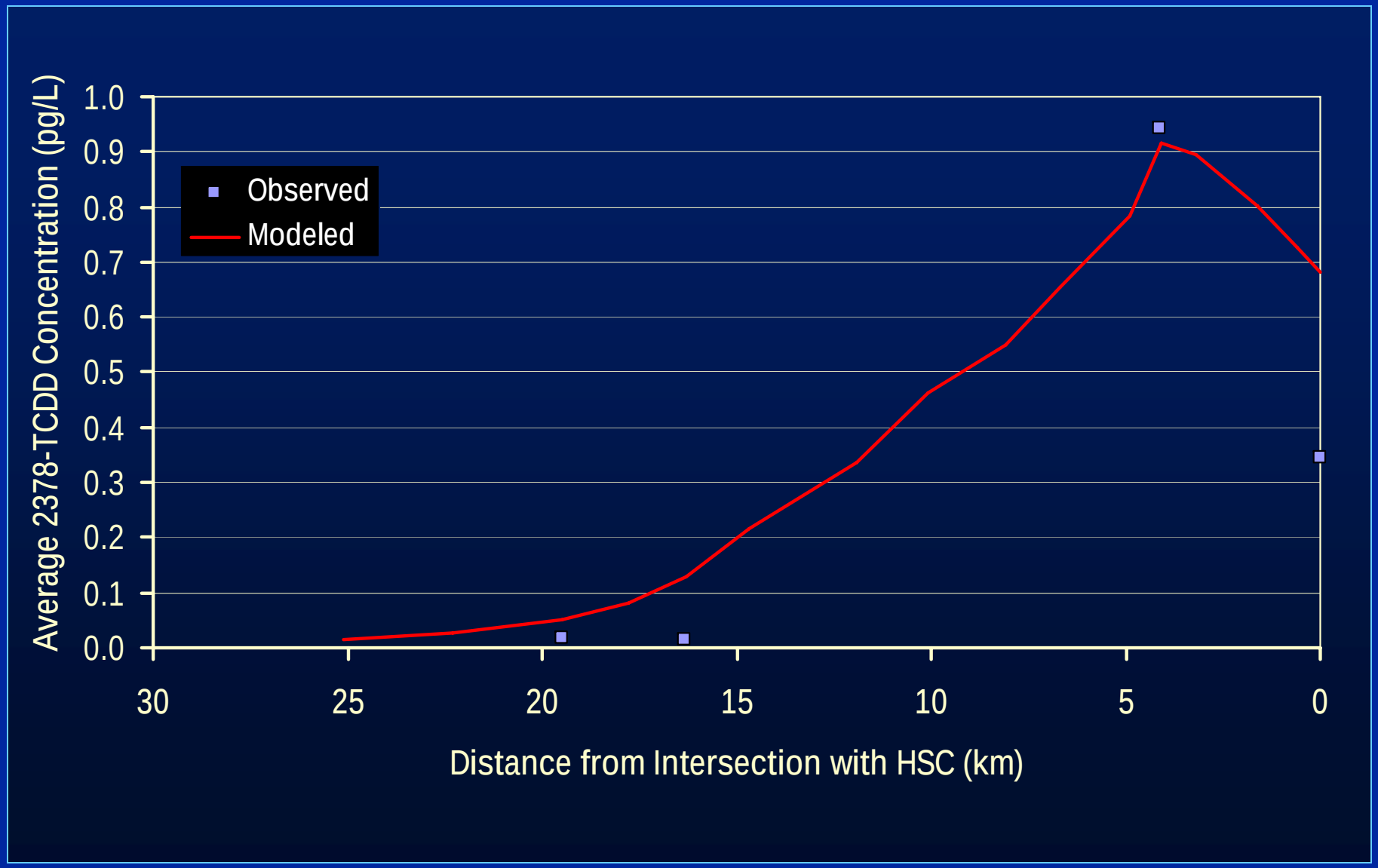
WASP 2378-TCDD model (2005)

- PS loads for direct discharges to WASP segments: $Q_{self\text{-}reported}$*Concentration
- NPS loads and PS discharging u/s model segments: $Q_{USGS\ gage}$*Concentration
  - Runoff concentration for rainy days
  - Tributary concentration for dry days
- Direct deposition: deposition flux*area
- March-April 2005 was generally a dry period so NPS are lower than expected for rest of year
- Long-term simulation will account for dry and wet periods

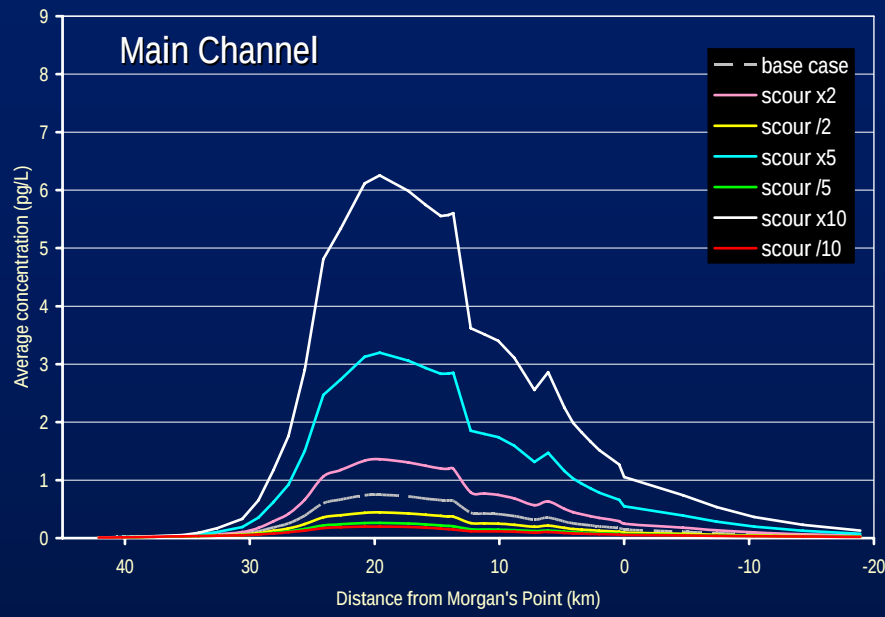
WASP 2378-TCDD model (2005) – main channel

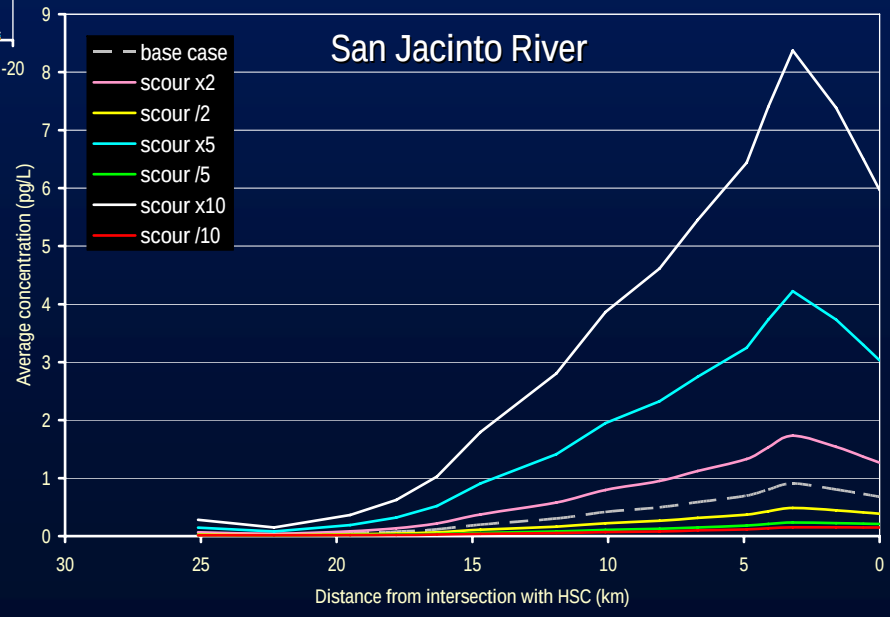


WASP 2378-TCDD model (2005) – San Jac

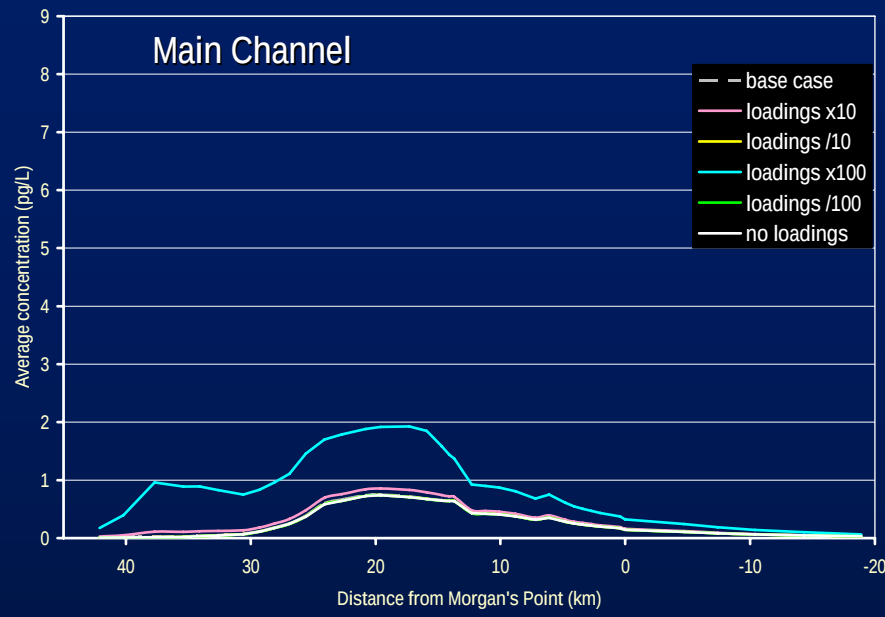


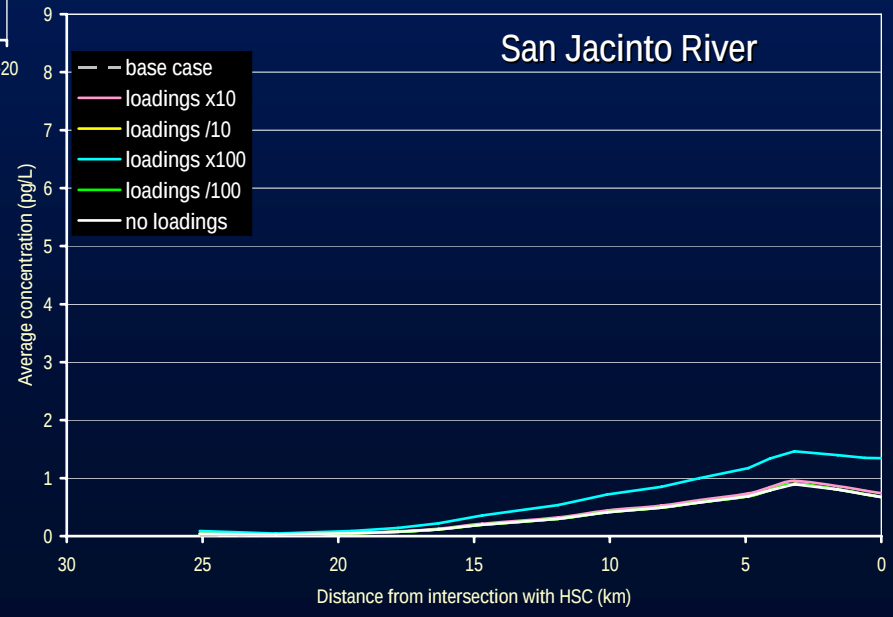
WASP sensitivity analysis – scour velocity



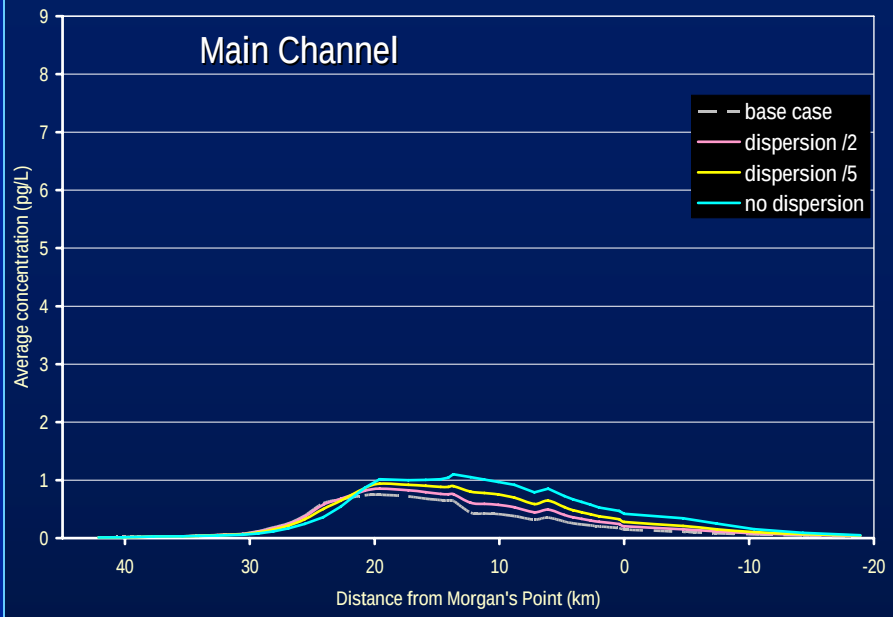


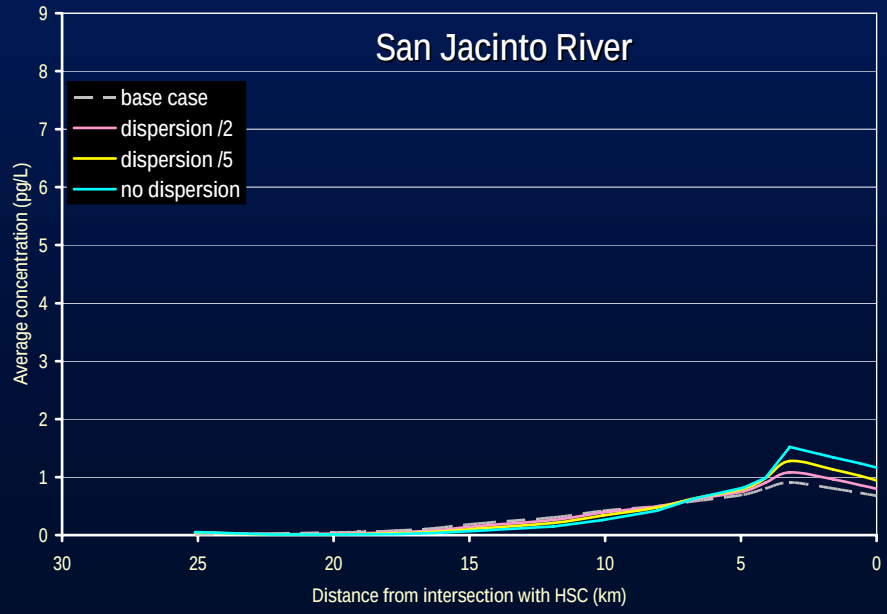
WASP sensitivity analysis – loading



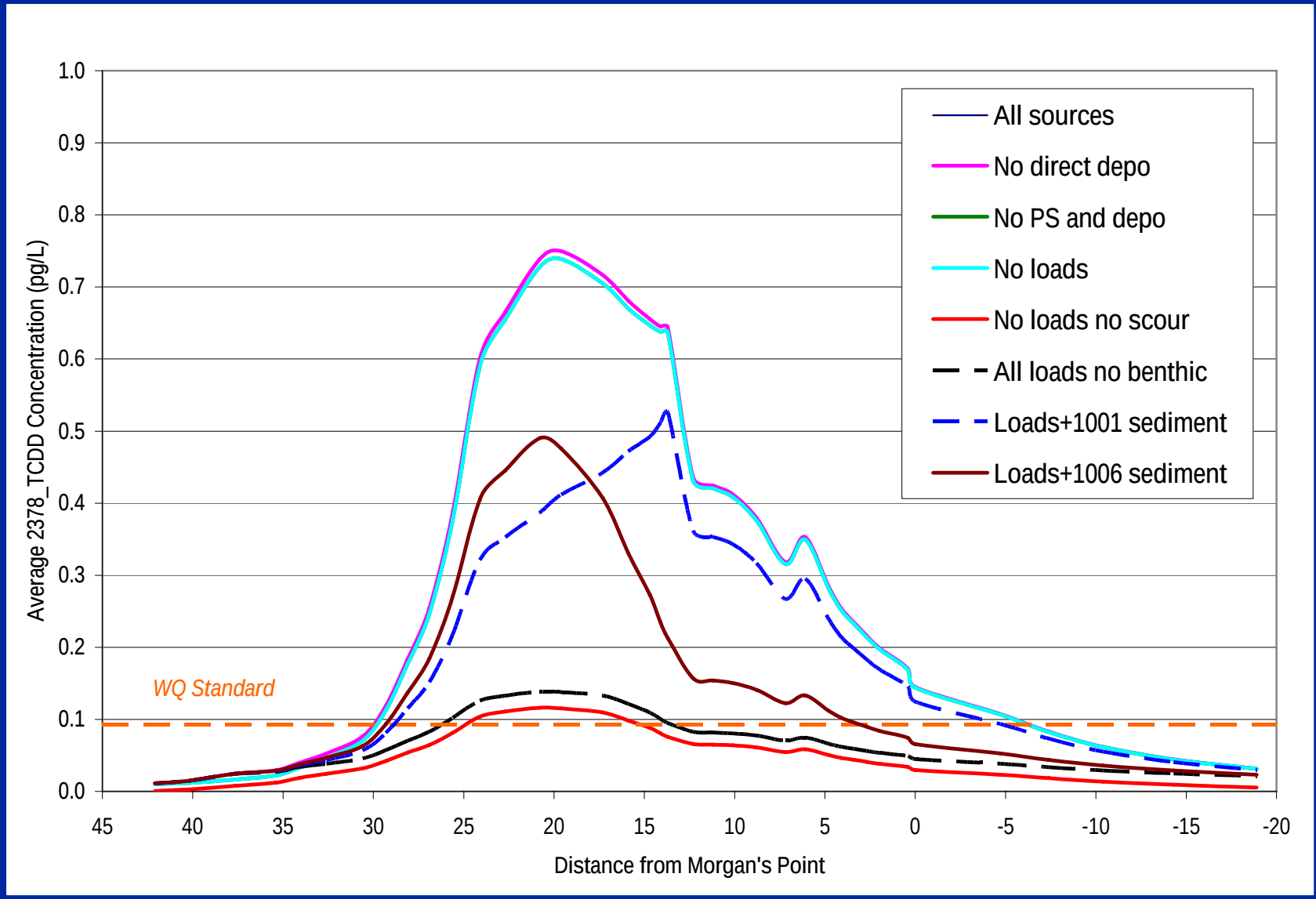


WASP sensitivity analysis – dispersion

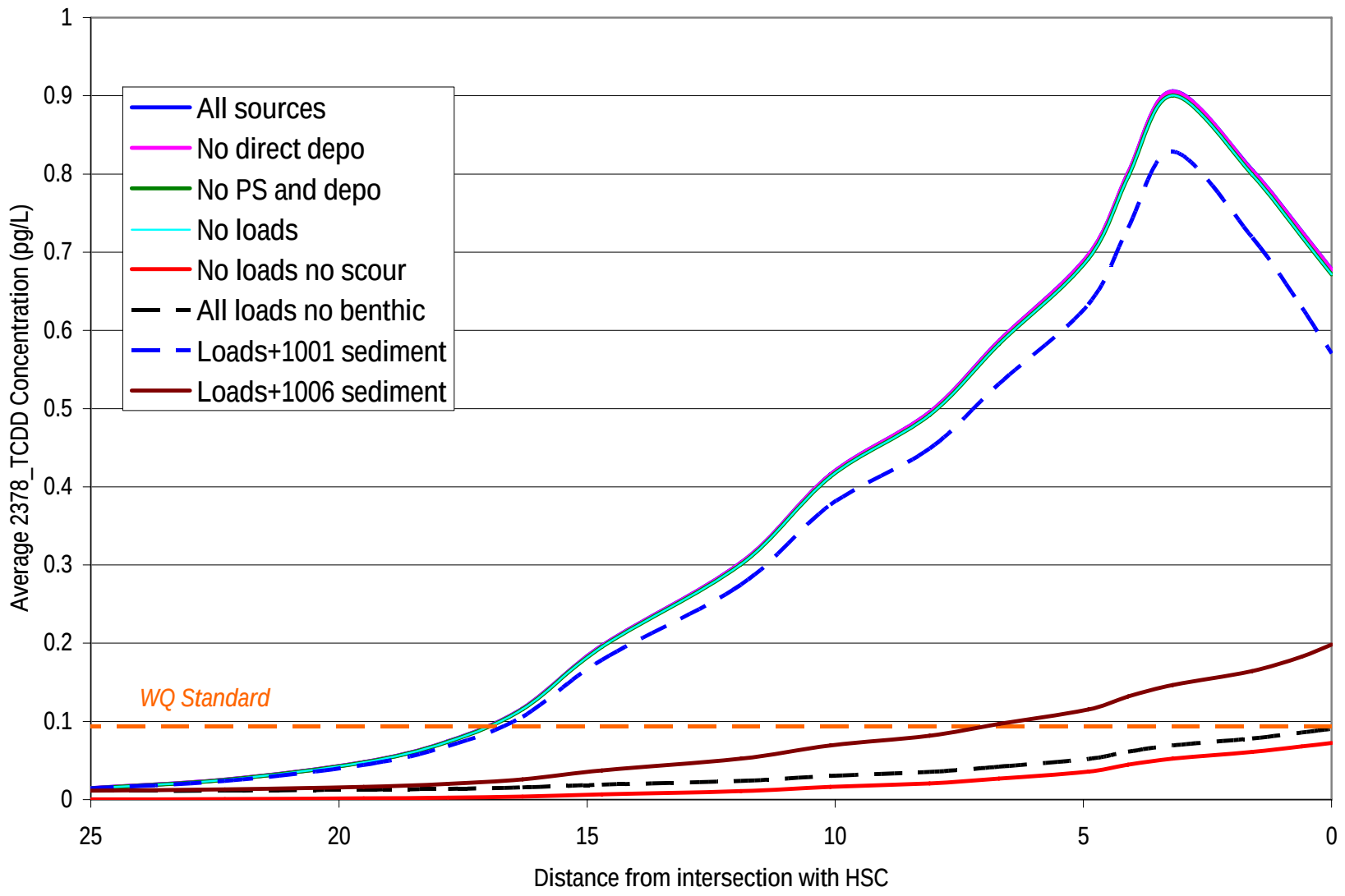




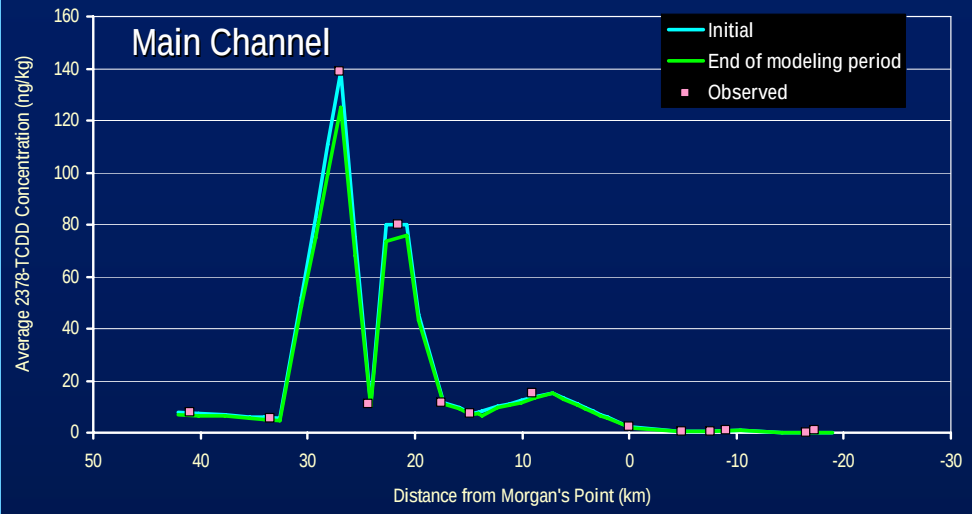
WASP load scenarios – main channel

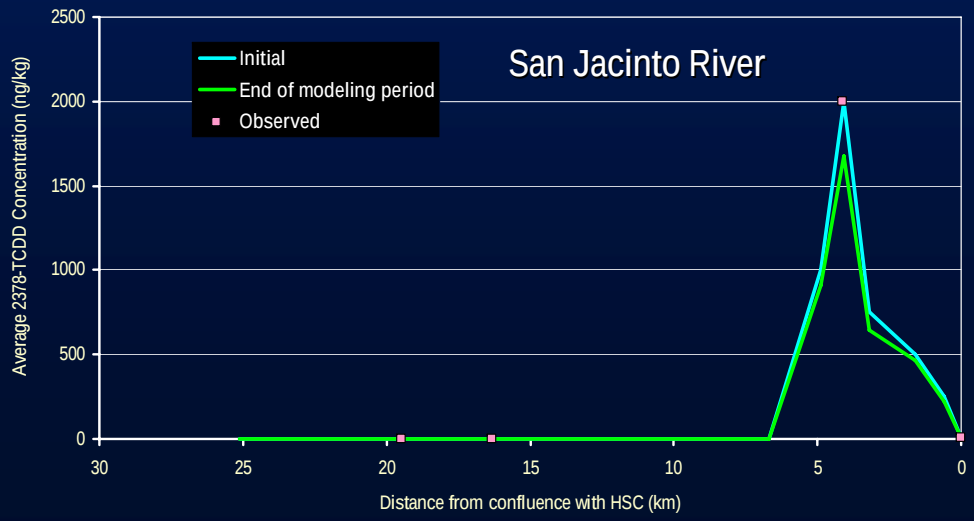


WASP load scenarios – main channel

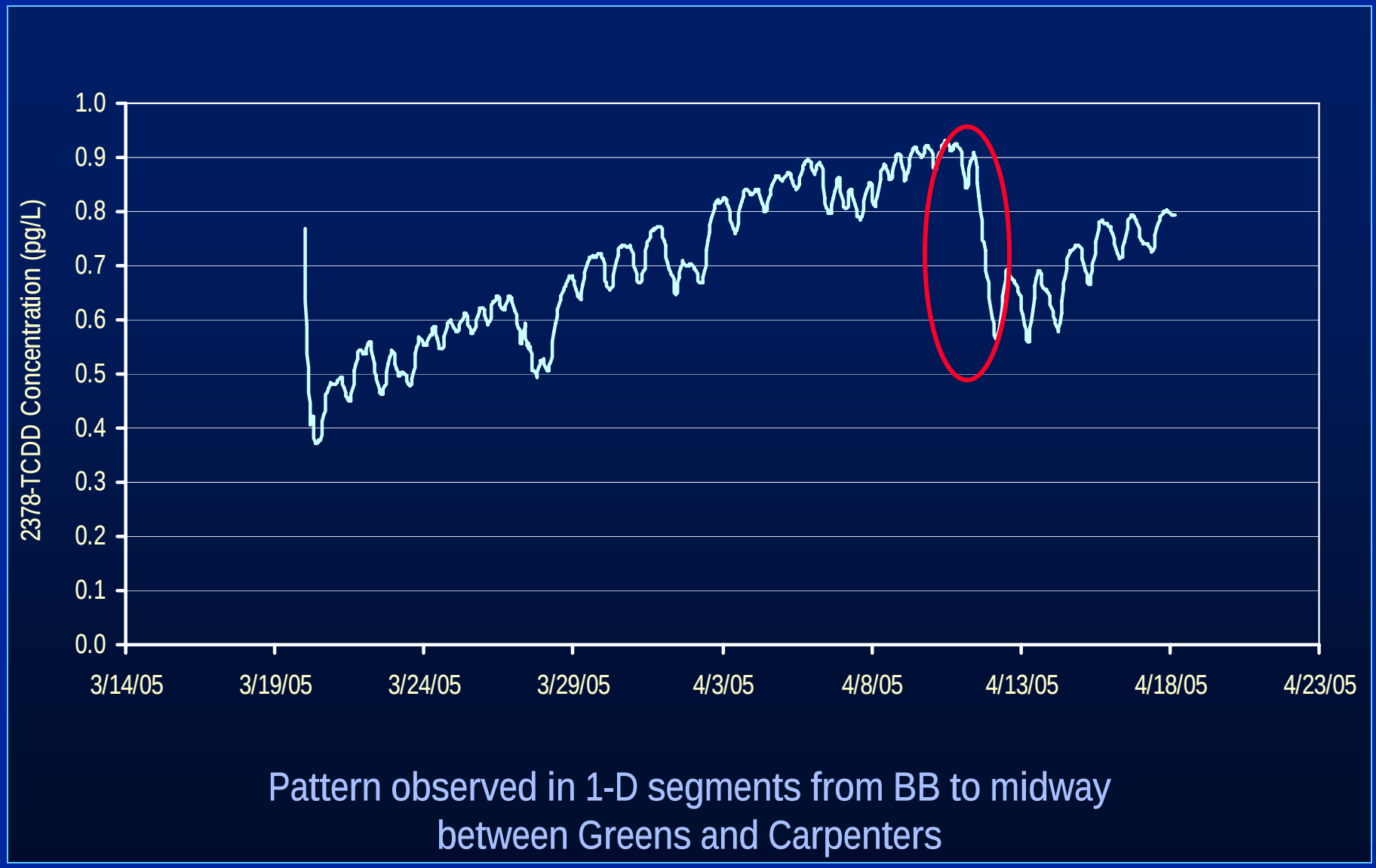


WASP benthic segments





WASP issues



Pattern observed in 1-D segments from BB to midway between Greens and Carpenters

Load allocation spreadsheet model

Point source load estimates

- 2378-TCDD and TEQ
- 5-year average of self-reported flows
- Dioxin concentrations
  - If effluent sampled in 2003, measured concentration
  - If only sludge measured in 2002, used sludge-effluent regression
  - If PS not sampled, average concentration for SIC code

Runoff load estimates

- 2378-TCDD and TEQ
- Flows determined using SCS curve method and average daily precipitation for year 2002 (total yearly precipitation divided by 365)
- Dioxin concentrations in runoff measured in 2003 and 2005 assigned by proximity to watersheds

Direct deposition load estimates

- 2378-TCDD and TEQ
- Deposition fluxes measured in this project (100% non-detects for 2378-TCDD)
  - Wet: 0.6 pg/m^2/day for 2378-TCDD and 10 pg/m^2/day for TEQ
  - Dry: 0.4 pg/m^2/day for 2378-TCDD and 2.4 pg/m^2/day for TEQ
- Fluxes multiplied by surface area of the water quality segments
- Non-detects assumed as ½ MDL

In-stream load estimates

- 2378-TCDD and TEQ
- Net flow out of each segment (average of flows simulated for the period March-April 2005 at downstream end of segments)
- Average water concentrations at locations where flow was measured
- Load for a given segment is load out of the segment minus load from upstream segments

Load spreadsheet – preliminary mass balance

Segment	In-stream load[a]	Source Loads (ng/day)			
		Point Sources	Stormwater Runoff	Direct deposition	Sediment?[b]
1014+1017	7,867	15,953	35,127	291	-43,504
1007	555,615	43,941	34,607	4,566	472,501
1016	27,736	7,434	30,633	581	-10,912
1006	1,430,737	19,275	4,673	6,259	1,400,529
1001 upper	145,107	4,071	47,568	4,644	88,824
1001 lower	7,185,593		15,856	1,548	7,168,189
2430	640		379	5,525	-5,264
Old River	1,170			516	654
2429	2,985		344	3,859	-1,219
2428	207		207	3,178	-3,177
2427	6,234	1,696	310	5,339	-1,111
2426	75,048	593	517	10,394	63,545
2436	465	50		268	147
1005	1,063,016	4,876	1,557	13,319	1,043,264
2438	4,807			677	4,130

[a] Average concentration measured in 2002-2004 times net flow out of segment

[b] Difference between in-stream load and the sum of loads from

Non-detects assumed equal to 1/2MDL for load calculations

Load spreadsheet – preliminary overall reduction

Segment	Net Flow[a] (m^3/s)	Allowable Load (ng/day)	In-stream Load (ng/day)	% Overall Reduction
1014+1017	10.3	8,341	7,867	0%
1007	24.7	19,944	555,615	96%
1016	5.4	4,357	27,736	84%
1006	30.8	24,847	1,430,737	98%
1001 upper	90.3	72,787	145,107	50%
1001 lower	90.1	72,637	7,185,593	99%
2430	0.05	38	640	94%
Old River	0.7	575	1,170	51%
2429	0.2	148	2,985	95%
2428	0.07	55	207	74%
2427	0.21	170	6,234	97%
2426	5.1	4,114	75,048	95%
2436	0.01	12	465	98%
1005	124.8	100,588	1,063,016	91%
2438	3.2	2,577	4,807	46%

[a] Average of simulated flows out of segment for period March-April 2005

Load spreadsheet – load reductions example1

WWTP Reduction	70%
Stormwater Runoff Reduction	70%
Direct Depo Reduction	70%
Sediment Load Reduction	90%

Segment	Net Flow[a] (m^3/s)	Allowable Load (ng/day)	Reduced Loads				Meet Allowable Load?
			Point Sources		Non-point Sources		
			WWTPs	Stormwater runoff (MS4s)	Direct deposition	Sediment?	
1014+1017	10.3	8,341	4,786	10,538	87	0	No
1007	24.7	19,944	13,182	10,382	1,370	47,250	No
1016	5.4	4,357	2,230	9,190	174	0	No
1006	30.8	24,847	5,783	1,402	1,878	140,053	No
1001 upper	90.3	72,787	1,221	14,270	1,393	8,882	Yes
1001 lower	90.1	72,637	0	4,757	464	716,819	No
2430	0.05	38	0	114	1,658	0	No
Old River	0.7	575	0	0	155	65	Yes
2429	0.2	148	0	103	1,158	0	No
2428	0.07	55	0	62	953	0	No
2427	0.21	170	509	93	1,602	0	No
2426	5.1	4,114	178	155	3,118	6,355	No
2436	0.01	12	15	0	80	15	No
1005	124.8	100,588	1,463	467	3,996	104,326	No
2438	3.2	2,577	0	0	203	413	Yes

[a] Average of simulated flows out of segment for period March-April 2005

Load spreadsheet – load reductions example2

WWTP Reduction	0%
Stormwater Runoff Reduction	0%
Direct Depo Reduction	0%
Sediment Load Reduction	95%

Segment	Net Flow[a] (m^3/s)	Allowable Load (ng/day)	Reduced Loads				Meet Allowable Load?
			Point Sources		Non-point Sources		
			WWTPs	Stormwater Runoff (MS4s)	Direct deposition	Sediment?	
1014+1017	10.3	8,341	15,953	35,127	291	0	No
1007	24.7	19,944	43,941	34,607	4,566	23,625	No
1016	5.4	4,357	7,434	30,633	581	0	No
1006	30.8	24,847	19,275	4,673	6,259	70,026	No
1001 upper	90.3	72,787	4,071	47,568	4,644	4,441	Yes
1001 lower	90.1	72,637	0	15,856	1,548	358,409	No
2430	0.05	38	0	379	5,525	0	No
Old River	0.7	575	0	0	516	33	Yes
2429	0.2	148	0	344	3,859	0	No
2428	0.07	55	0	207	3,178	0	No
2427	0.21	170	1,696	310	5,339	0	No
2426	5.1	4,114	593	517	10,394	3,177	No
2436	0.01	12	50	0	268	7	No
1005	124.8	100,588	4,876	1,557	13,319	52,163	Yes
2438	3.2	2,577	0	0	677	206	Yes

[a] Average of simulated flows out of segment for period March-April 2005

Summary

- Hydrodynamic model finished (6 min timestep), a few mass-balance issues remain
- Runoff loads entered to WASP as the measured concentrations (dry and runoff) and USGS flows
- WASP model very sensitive to sediment-related parameters
- Preliminary dioxin results indicate source in 1001 affects dioxin levels in 1006
- Preliminary load calculations and model results indicated major contribution from sediment

Next steps

- Address remaining RMA2/WASP issues
- Calibrate dioxin model to concentrations measured between 2002 and 2004 (long-term run)
- Refine scour and settling models
- Run load reduction scenarios
- Update load spreadsheet model and define TMDL