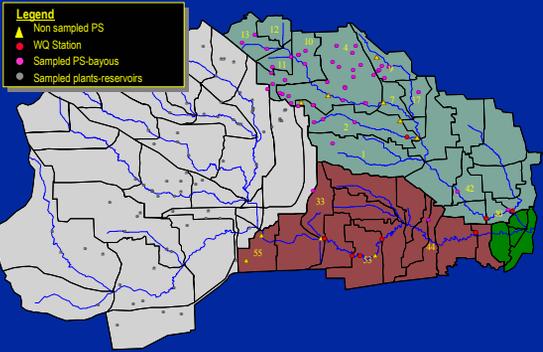


Total Maximum Daily Load for Fecal Pathogens in Buffalo Bayou and Whiteoak Bayou

Key Issues

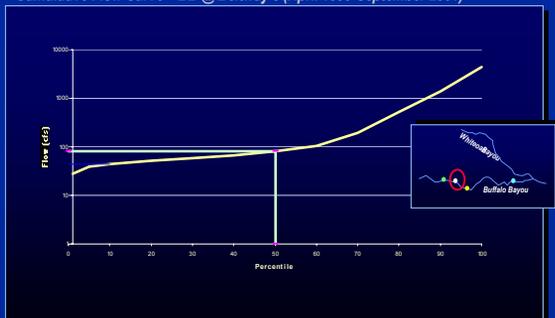
University of Houston
PBS&J

Point Sources



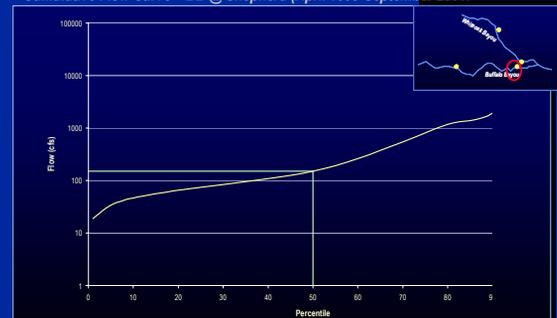
Point Sources

Cumulative Flow Curve – BB @ Beltway 8 (April 1999-September 2001)



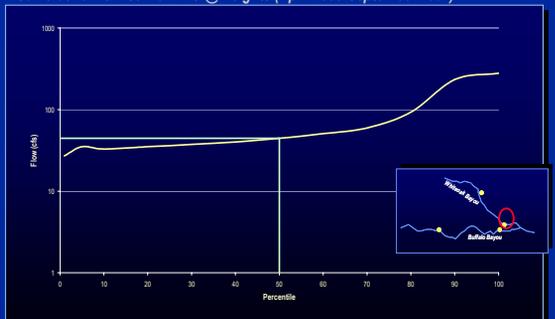
Point Sources

Cumulative Flow Curve – BB @ Shepherd (April 1999-September 2001)



Point Sources

Cumulative Flow Curve – WO @ Heights (April 1999-September 2001)



Flow from Point Sources (cfs)

Watershed	Station	April 1999-September 2001		Summer		7Q2 ²
		50% Flow	WWTP ¹	50%	WWTP ¹	
Buffalo Bayou	Barker Reservoir	32	12.9	31	13.3	-
	Addicks Reservoir	41	17.4	40	17.7	-
	West Bell Gage	81	52.0	76	52.8	43.3
	Shepherd Gage ³	151	55.5	123	56.3	25.4
Whiteoak Bayou	Heights Gage	40	29.5	44	31.1	29.1

¹ Calculated using model WWTP data
² Period of record for 7Q2 ranges from 1962-1975 for Shepherd gage and 1980's-1996 for other gages (data from TCEQ)
³ Shepherd gage is tidally influenced and only records higher flow events

Loads from Point Sources (MPN/day)

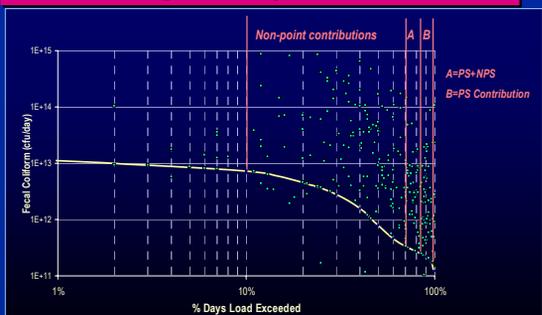
Watershed	Station	April 1999-September 2001			Summer
		Bayou	WWTP ¹	Unpermitted	Bayou
Buffalo Bayou	Barker Reservoir	-	1.51x10 ⁹	-	-
	Addicks Reservoir	-	2.77x10 ⁹	-	-
	West Bell Gage	3.72x10 ¹³	6.93x10 ⁹	1.88x10 ¹⁰	6.92x10 ¹³
	Shepherd Gage ³	1.31x10 ¹⁴	6.94x10 ⁹	2.16x10 ¹¹	1.94x10 ¹⁴
Whiteoak Bayou	Heights Gage	8.12x10 ¹³	1.82x10 ¹⁰	1.98x10 ¹¹	9.48x10 ¹³

¹ WWTP Loads calculated using model flow EC data. EC concentrations for plants in reservoir calculated same as for model.

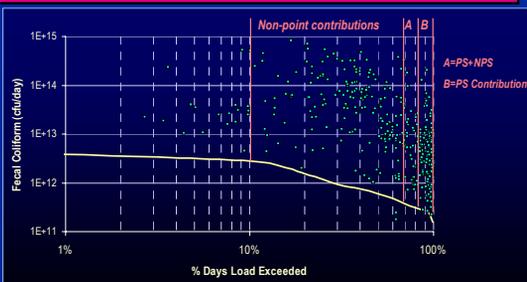
Non-point Sources

- Build-up and wash-off
- Sediment
 - Resuspension
 - Die-off
- Wildlife

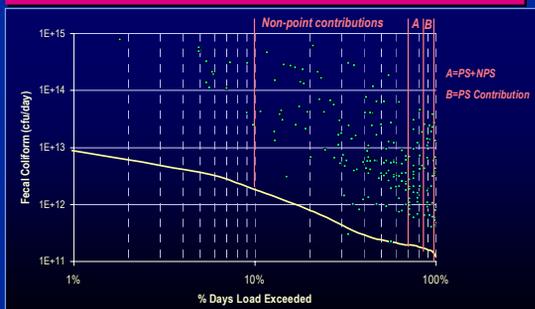
Point vs Non-point Sources: TMDL Curve - BB @ Beltway 8



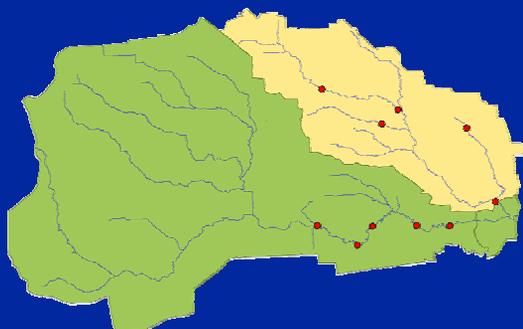
Point vs Non-point Sources: TMDL Curve - BB @ Shepherd



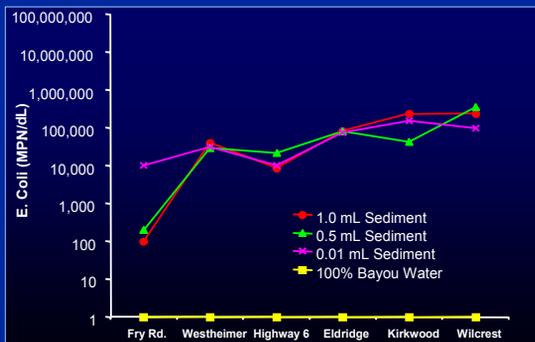
Point vs Non-point Sources: TMDL Curve - WO @ Heights



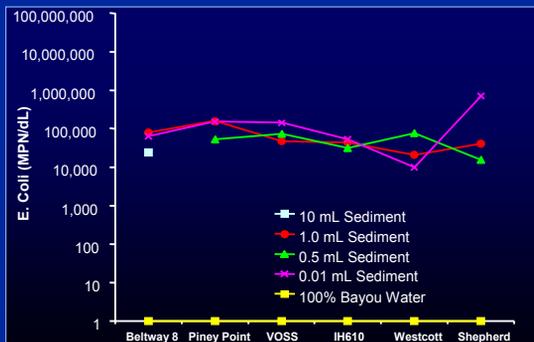
Bacteria in Sediment



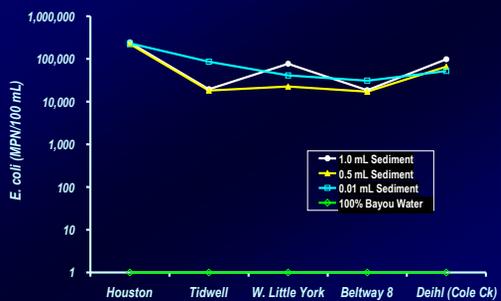
EC in BB sediments



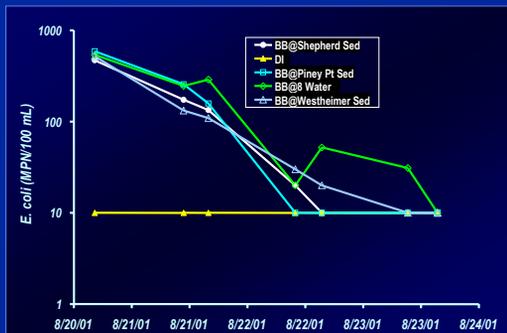
EC in BB sediments (cont'd)



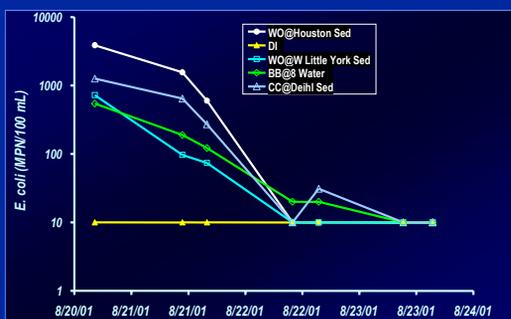
EC in WO sediments



BB sediment resupply



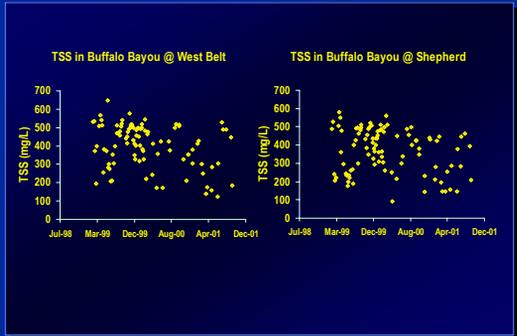
WO sediment resupply



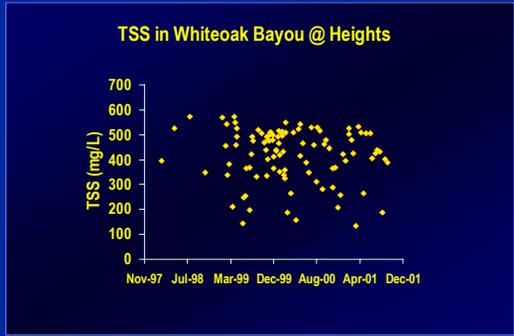
Summary Results of Sediment Sampling

	Geomean EC (MPN/dL)	Maximum EC (MPN/dL)	Minimum EC (MPN/dL)
Buffalo Bayou	54,884	155,307	20,750
Whiteoak Bayou	57,069	223,970	18,500

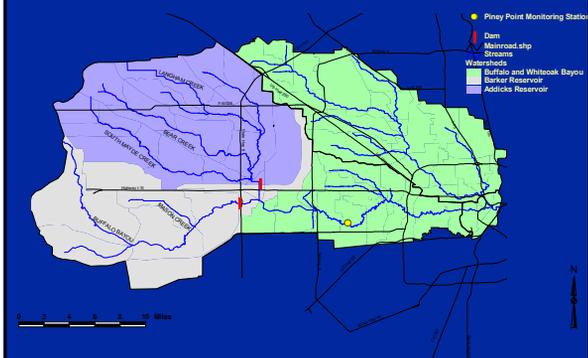
TSS Data in Buffalo Bayou



TSS Data in Whiteoak Bayou



Reservoirs in Buffalo Bayou

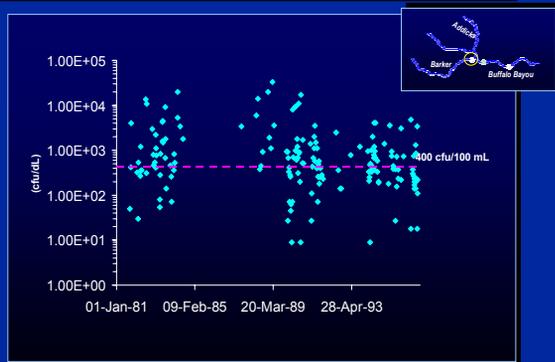


Reservoir Historical Data – USGS

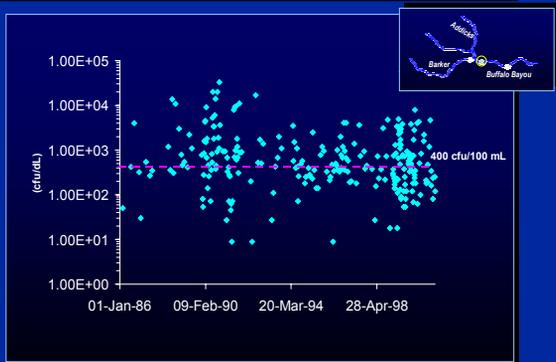
Reservoir	Location	Mean FC (cfu/dL)
Addicks	Tributaries	6307
	Reservoir	1090
	Discharge	737
Barker	Tributaries	3220
	Reservoir	763
	Discharge	663

Source: USGS WRI 86-4356, 1987. Samples collected from 1978-1981.

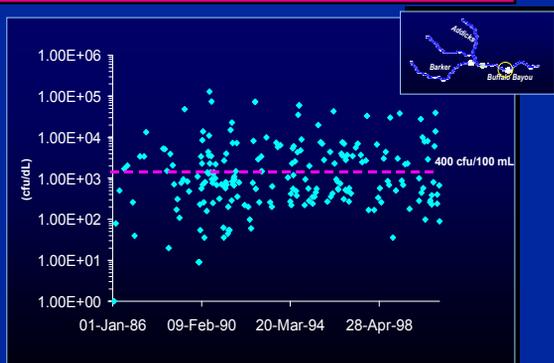
Time Series of FC Data at Barker Dam



Time Series of FC Data at Hwy 6



Time Series of FC Data at Dairy Ashford

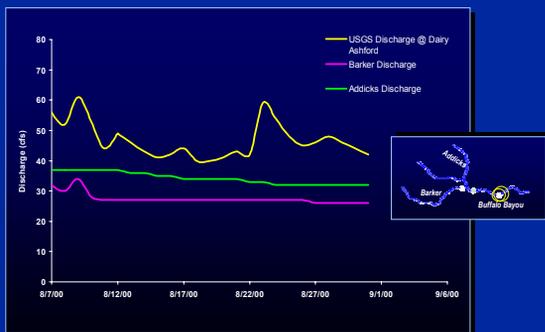


Downstream Monitoring Stations

	Range	N	Geo Mean	% > Std ¹
Barker Dam	9 – 58,000	122	899	71%
Highway 6	9 – 58,000	232	579	59%
Dairy Ashford	9 – 130,000	185	1,263	72%

¹ regulatory limits: 400 cfu/dL for FC. All the values given as FC in cfu/dL. Data from 1990 onward.

Dry weather Reservoir and Dairy Ashford Hydrograph



Reservoir Summary

- Historically high levels of fecal coliform are observed within and downstream of the reservoirs
- Reservoirs are attenuating the bacteria levels
- During dry weather conditions, most of the upstream bayou flow originates from the reservoirs
- Reservoirs are treated as a single input in the TMDL

Low flow vs high flow

TMDL Equation

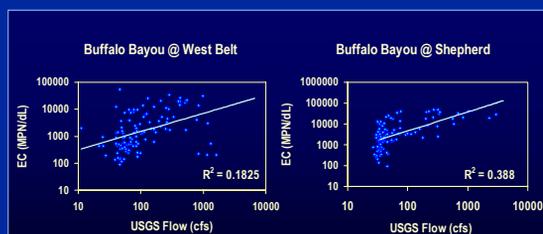
$$LC = WLA + LA + MOS$$

LC = loading capacity
 WLA = wasteload allocation
 LA = load allocation
 MOS = margin of safety

At what flow? Safe contact recreation based low flow?

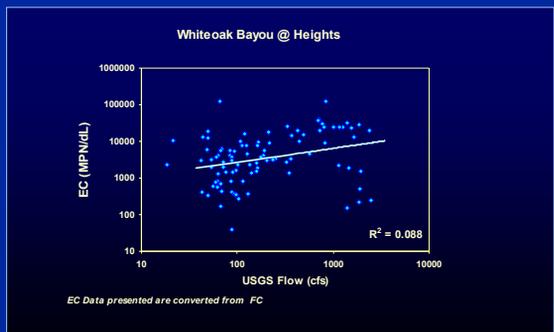
Withdrawal issues? By-pass structure? BB redevelopment?

Flow vs EC in BB



EC data presented are converted from FC

Flow vs EC in WO



Low Flow – High Flow



Load Allocation Scenarios

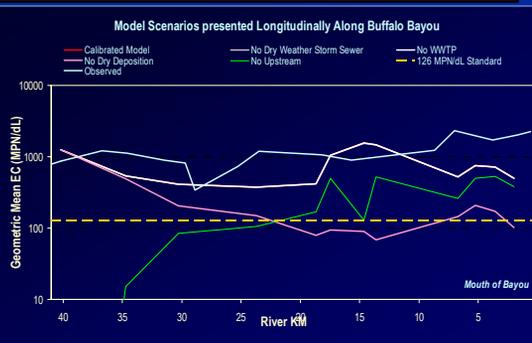
Eliminate Unpermitted Stormwater EC Discharges

Eliminate Wastewater Treatment Plant EC Discharges

Eliminate Wildlife NPS Accumulation of EC

Eliminate Upstream EC Inflow (Buffalo Bayou)

Summary BB Allocation Scenarios



Summary WO Allocation Scenarios



BMPs

Many options to be evaluated:

- Detention/irrigation systems
- Inlet devices
- Grassy swales
- Infiltration/exfiltration trenches
- Vegetative filter strips
- Overflow regulating modules
- Sand filter systems
- Educational and governmental programs
- Constructed wetlands
- Alum Treatment systems
- Baffle boxes

Other issues

- Stakeholders
- Timeline

Total Maximum Daily Load for Fecal Pathogens in Buffalo Bayou and Whiteoak Bayou

University of Houston
PBS&J

Texas Freshwater Bacteria Standards

<i>E. coli</i>	Geometric Mean	126 MPN/100 mL
	Not-to-Exceed	394 MPN/100 mL
<i>Fecal coliform</i>	Geometric Mean	200 cfu/100 mL
	Not-to-Exceed	400 cfu/100 mL

Major Tasks WO1

- Stakeholder/Public education and involvement
- Assess current levels and trends of bacterial indicators of fecal pathogens in the bayous
- Assess major sources, transport, and fate of bacterial indicators of fecal contamination
- Apply models to elucidate the sources and major processes controlling observed levels of FC
- Develop a QAPP for additional data collection

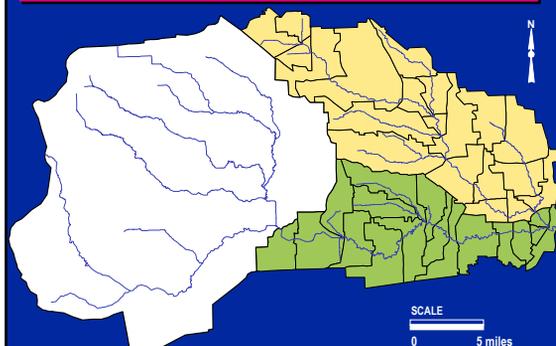
Major Tasks WO2

- Stakeholder/Public education and involvement
- Assess current levels and trends of bacterial indicators of fecal pathogens in the bayous
- Assess major sources, transport, and fate of bacterial indicators of fecal contamination
- Apply models to elucidate the sources and major processes controlling observed levels of FC
- TMDL allocation analysis

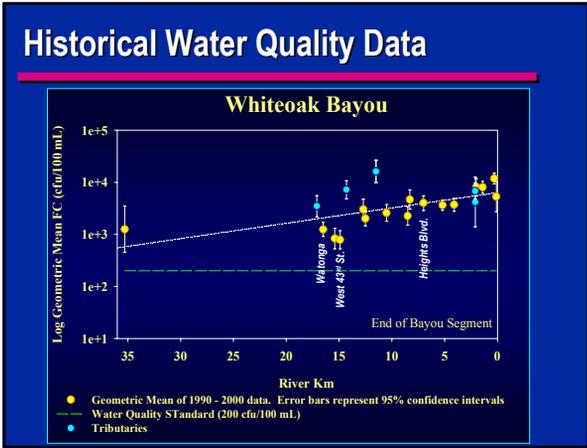
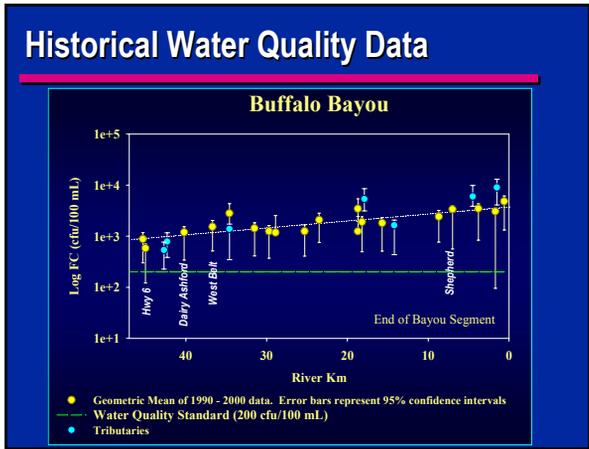
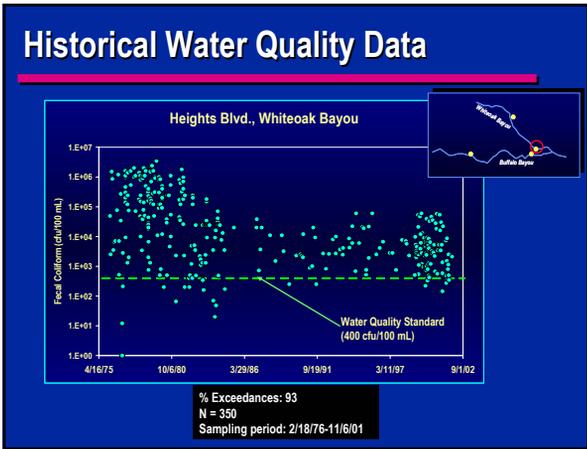
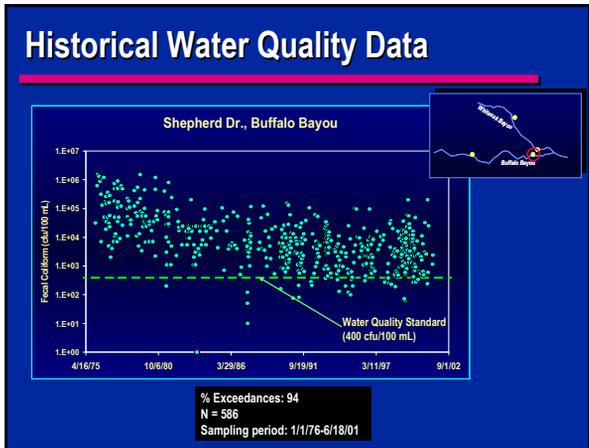
Major Tasks WO5

- Stakeholder/Public education and involvement
- Providing information and support to TCEQ TMDL Team to complete the TMDL
- Providing information and support to TCEQ TMDL Team for Implementation Plan development

Buffalo and Whiteoak Bayous



Results from WO1



Results from WO2

Potential Sources of EC in Buffalo and Whiteoak Bayous

Incomplete disinfection from WWTP effluent (possible regrowth)

Non-point sources (sediment, accumulation/washoff, birds)

Dry-weather pipe discharges

By-passes, overflows, wet-weather facilities

Upstream bacteria sources (Addicks and Barker reservoirs - Buffalo Bayou Only)

Solids releases from WWTPs

Potential Sources of EC in Buffalo and Whiteoak Bayous

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Non-point sources (sediment, accumulation/washoff, birds)

Dry-weather pipe discharges

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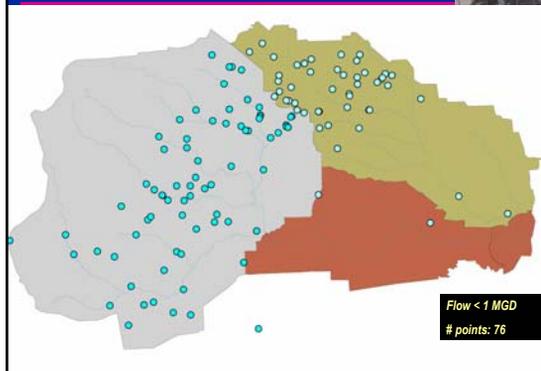
Upstream bacteria sources (Addicks and Barker reservoirs - Buffalo Bayou Only)

Solids releases from WWTPs

Wastewater Treatment Plant Sampling



WWTP Sampling



Results of WWTP sampling

	All samples (n=152)		Peak flow samples (n=80)		Off-peak flow samples (n=72)	
	EC	FC	EC	FC	EC	FC
Geomean	3	<1	3	<1	2	<1
Range	<1- >2,347	<1-5,000	<1- >2,347	<1-5,000	<1-759	<1-150
% >std¹	7%	2%	9%	4%	6%	0%

¹ regulatory limits: 126 MPN/dL for EC and 200 cfu/dL for FC
EC values given in MPN/dL and FC in cfu/dL

Potential Sources of EC in Buffalo and Whiteoak Bayous

Incomplete disinfection from WWTP effluent (possible regrowth)

Non-point sources (sediment, accumulation/washoff, birds)

Dry-weather pipe discharges

By-passes, overflows, wet-weather facilities

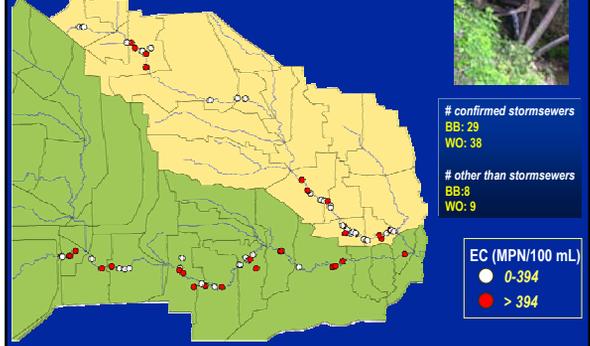
Upstream bacteria sources (Addicks and Barker reservoirs - Buffalo Bayou Only)

Solids releases from WWTPs

Dry-weather Pipe Discharge Sampling



Dry-weather Inflows Sampling



Results of Dry-weather Inflows Sampling

	All samples (n=84)		Buffalo Bayou (n=37)		Whiteoak Bayou (n=47)	
	EC	FC	EC	FC	EC	FC
Geomean	260	63	200	31	136	77
Range	<1->241,920	<1-26,000	17->241,920	<1-26,000	12->241,920	<1-20,000
% >std¹	53%	43%	57%	50%	50%	37%

¹ regulatory limits: 126 MPN/dL for EC and 200 cfu/dL for FC
EC values given in MPN/dL; FC values given in cfu/dL

E. coli load for WWTP and Dry-weather Inflows

	WWTP Load (MPN/yr)	DWI Load (MPN/yr)
Buffalo Bayou	1.82E+12	7.89E+13
Whiteoak Bayou	5.83E+14	7.24E+13
Total	5.85E+14	1.51E+14

DWI = dry-weather inflows; MPN = most probable number

Potential Sources of EC in Buffalo and Whiteoak Bayous

Incomplete disinfection from WWTP effluent (possible regrowth)

Non-point sources (sediment, accumulation/washoff, birds)

Dry-weather pipe discharges

By-passes, overflows, wet-weather facilities

Upstream bacteria sources (Addicks and Barker reservoirs - Buffalo Bayou Only)

Solids releases from WWTPs

Reservoirs in Buffalo Bayou

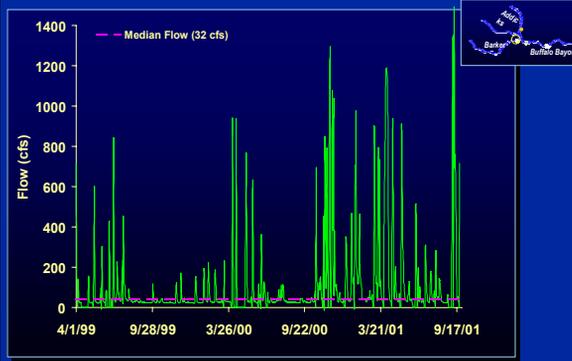


Reservoir Historical Data – USGS

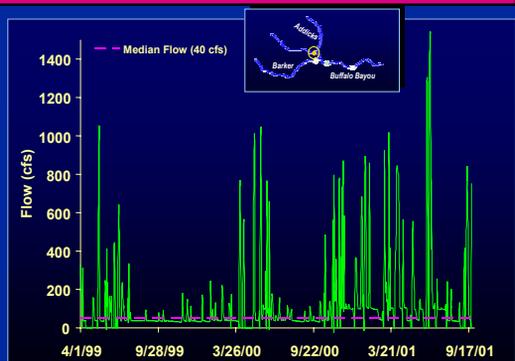
Reservoir	Location	Mean FC (cfu/dL)
Addicks	Tributaries	6307
	Reservoir	1090
	Discharge	737
Barker	Tributaries	3220
	Reservoir	763
	Discharge	663

Source: USGS WRI 86-4356, 1987. Samples collected from 1978-1981.

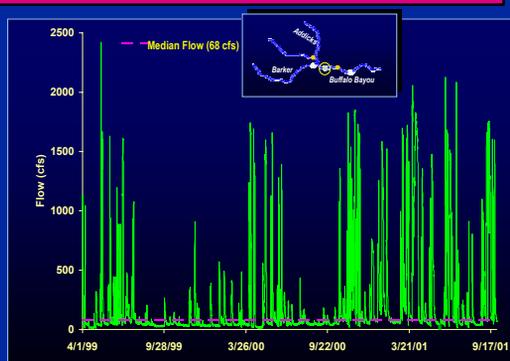
Flow at Barker Dam



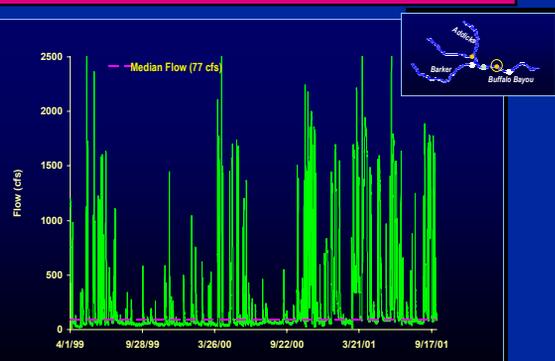
Flow at Addicks Dam



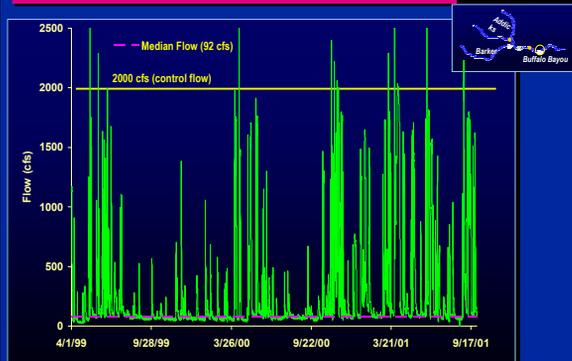
Flow at Dairy Ashford



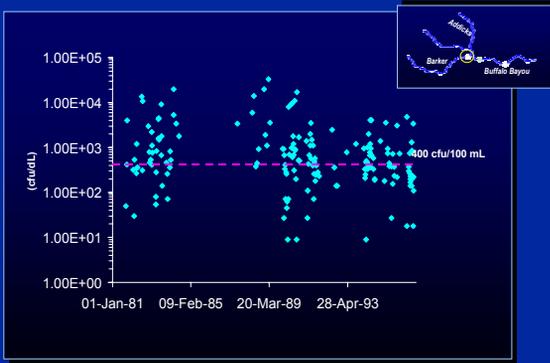
Flow at West Belt



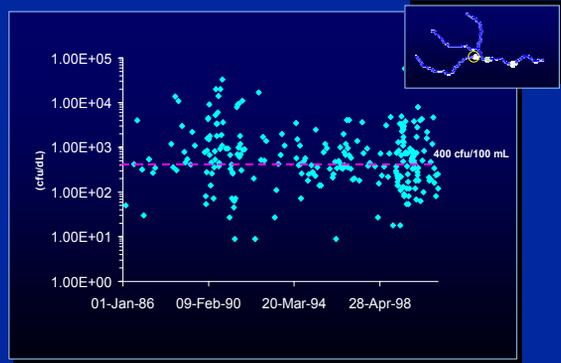
Time Series of Flow at Piney Point



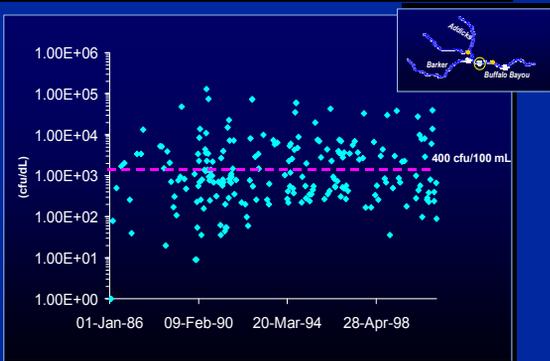
Time Series of FC Data at Barker Dam



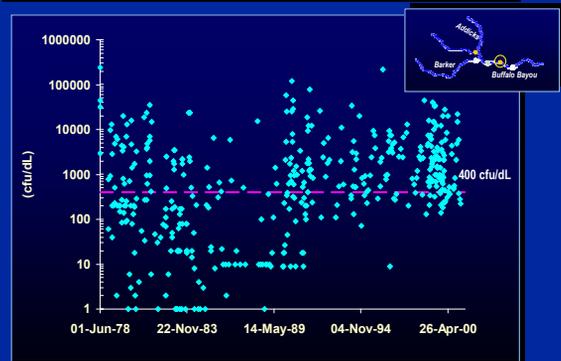
Time Series of FC Data at Hwy 6



Time Series of FC Data at Dairy Ashford



Time Series of FC Data at West Belt



FC downstream of reservoirs

	Range	N	Geo Mean	% > Std ¹
Barker Dam	9 – 58,000	122	899	71%
Highway 6	9 – 58,000	232	579	59%
Dairy Ashford	9 – 130,000	185	1,263	72%
West Belt	1-240,000	428	540	59%

¹ regulatory limits: 400 cfu/dL for FC. All the values given as FC in cfu/dL. Data from 1990 to current for Hwy6, DA and WB. Data for Barker from 1981 to 1993.

Upstream/Reservoirs - Summary

- Historically high levels of fecal coliform are observed within and downstream of the reservoirs
- Reservoirs are attenuating the bacteria levels
- During dry weather conditions, most of the upstream bayou flow originates from the reservoirs
- Reservoirs are treated as a single input in the TMDL

Potential Sources of EC in Buffalo and Whiteoak Bayous

Incomplete disinfection from WWTP effluent (possible regrowth)

Non-point sources (sediment, accumulation/washoff, birds)

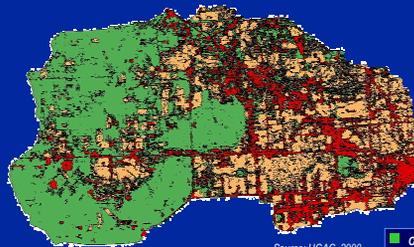
Dry-weather pipe discharges

By-passes, overflows, wet-weather facilities

Upstream bacteria sources (Addicks and Barker reservoirs - Buffalo Bayou Only)

Solids releases from WWTPs

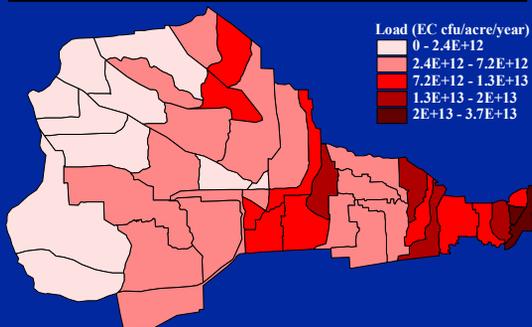
Landuse in Buffalo and Whiteoak Bayous



Source: HGAC, 2000

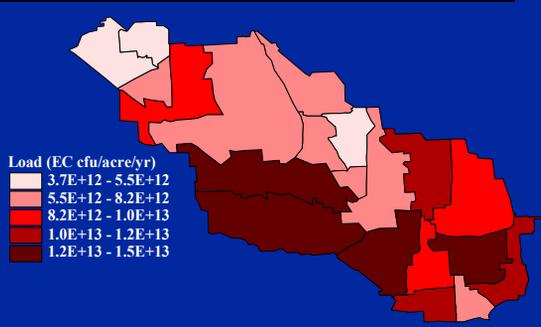
Open land
Residential
Commercial
Water

Non-point Source Loads - BB



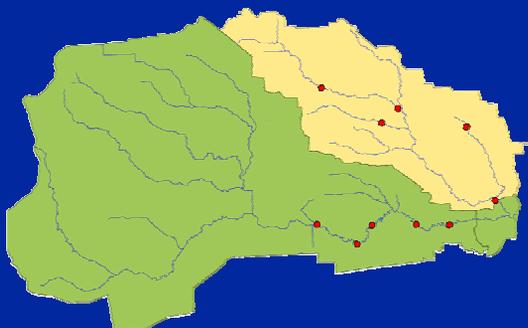
Loads calculated using EMC values from Characterization of Non-Point Sources and Loadings to Galveston Bay (Newell et al., 1992) with the PLOAD tool from BASINS 3.0

Non-point Source Loads - WOB



Loads calculated using EMC values from Characterization of Non-Point Sources and Loadings to Galveston Bay (Newell et al., 1992) with the PLOAD tool from BASINS 3.0

Results of Sediment Sampling

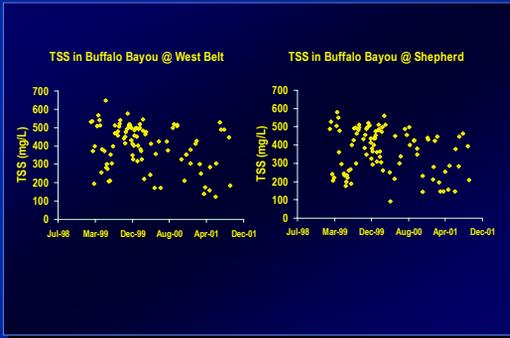


Results of Sediment Sampling

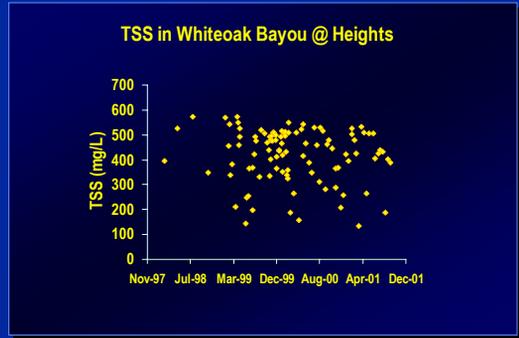
	Geomean EC (MPN/dL)	Maximum EC (MPN/dL)	Minimum EC (MPN/dL)
Buffalo Bayou (n=5)	54,884	155,307	20,750
Whiteoak Bayou (n=5)	57,069	223,970	18,500

Results per dL of sediment

TSS Data in Buffalo Bayou



TSS Data in Whiteoak Bayou



Potential Sources of EC in Buffalo and Whiteoak Bayous

Incomplete disinfection from WWTP effluent (possible regrowth)

Non-point sources (sediment, accumulation/washoff, birds)

Dry-weather pipe discharges

By-passes, overflows, wet-weather facilities

Upstream bacteria sources (Addicks and Barker reservoirs - Buffalo Bayou Only)

Solids releases from WWTPs

Loads from Self-reporting Overflows and By-passes

	Load (MPN/yr)	Reporting Period
Buffalo Bayou	1.9E+12	Oct-97 to Dec-02
Whiteoak Bayou	6.1E+11	Dec-00 to Dec-02
Total	2.5E+12	

Calculated using the total self-reporting volume times an FC concentration of 500,000 cfu/dL (raw sewage) and times 126/200 (to convert FC to EC)
No wet-weather facilities discharging to either Bayou

Potential Sources of EC in Buffalo and Whiteoak Bayous

Incomplete disinfection from WWTP effluent (possible regrowth)

Non-point sources (sediment, accumulation/washoff, birds)

Dry-weather pipe discharges

By-passes, overflows, wet-weather facilities

Upstream bacteria sources (Addicks and Barker reservoirs - Buffalo Bayou Only)

Solids releases from WWTPs

Summary Information on Solids Releases

- Inspection reports gathered from TCEQ local office on solid release occurrences (2)
- Information regarding TCEQ observed plant washouts difficult to quantify
- Data do not include volume discharged or bacteria levels
- Additional data for other bayous may be used to quantify EC loads

Relative Loads from PS and NPS

	BB	WOB
WWTP effluent	1.8×10^{12}	5.8×10^{14}
Dry-weather pipe discharges	7.9×10^{13}	7.2×10^{13}
Addicks & Barker drainage area	1.2×10^{15}	NA
NPS	1.2×10^{18}	6.7×10^{17}
By-passes & overflows	1.9×10^{12}	6.1×10^{11}
Potential solid releases	NC	NC

NA = not applicable; NC = not calculable (insufficient data); Loads in MPN/year

Results from Modeling in WO2 and WO5

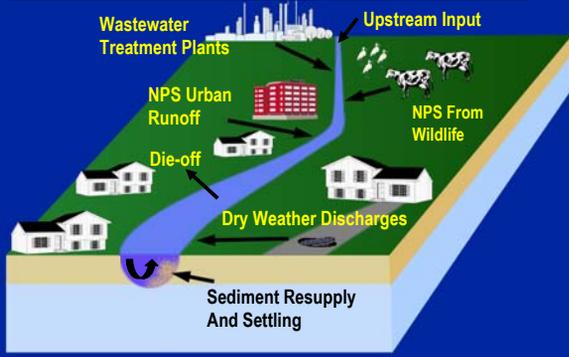
HSPF TMDL Model

- Build-up and wash-off of EC in watershed
- First-order decay of EC in sediment and water
- Scour and deposition of sediments in the bayous

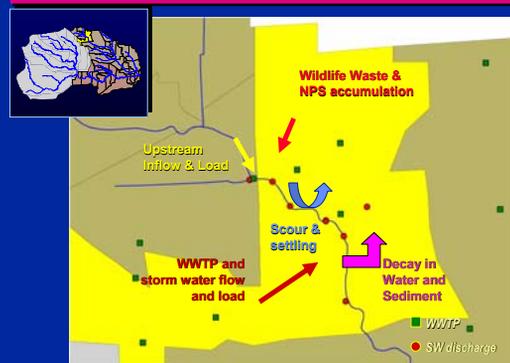
Model Development

- 1 Develop conceptual model
- 2 Data gathering and compilation
- 3 Model development
- 4 Hydrology calibration
- 5 EC calibration
- 6 Sensitivity analysis
- 7 Load allocation scenarios

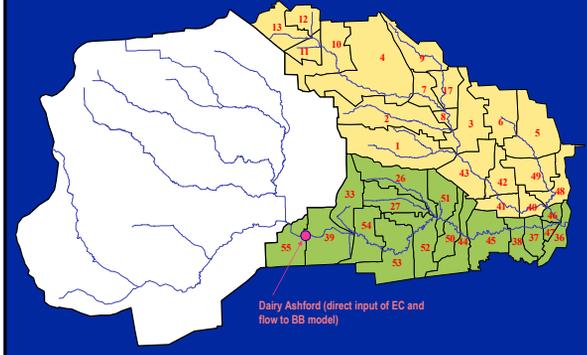
Conceptual Model



HSPF Subwatershed Conceptual Model



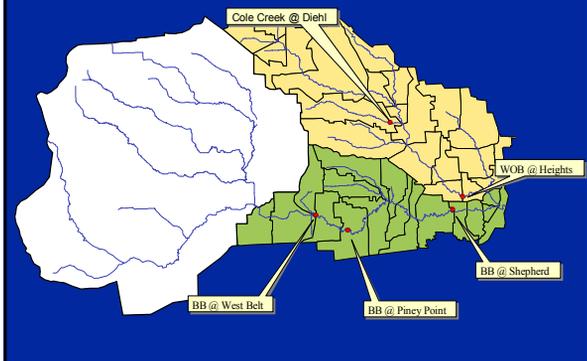
Model Subwatersheds



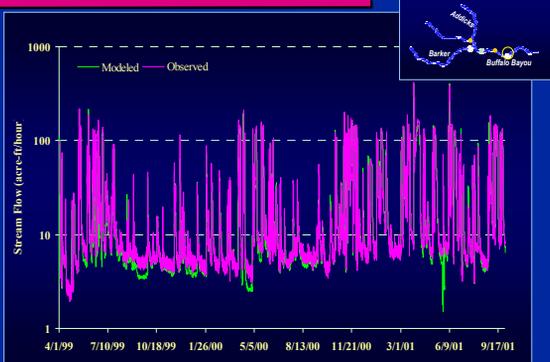
Flow Sources

- 1 Rainfall-runoff
- 2 WWTP effluent (average 5-yr self-reporting data)
- 3 Dry-weather pipe discharges (measured in Summer 2001)
- 4 Reservoir discharges

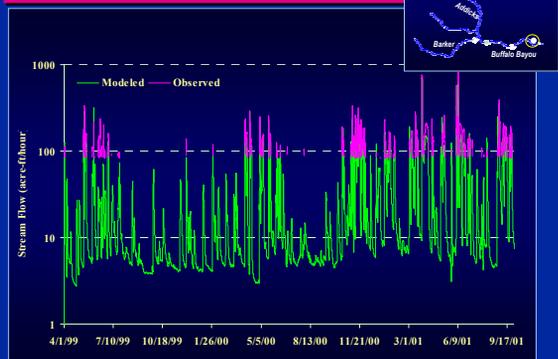
Hydrology Calibration Sites



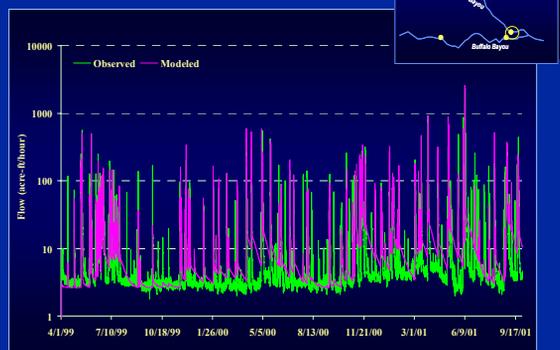
Flow Calibration - BB @ Piney Point



Flow Calibration - BB @ Shepherd



Flow Calibration - WO @ Heights



Flow Calibration – Buffalo Bayou

	West Belt	Piney Point	Shepherd
Total Volume	-10%	-5%	-24%
10 th Percentile	-27%	-17%	-30%
90 th Percentile	-11%	-5%	-16%

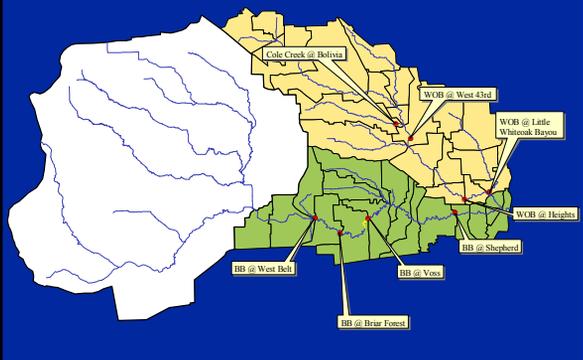
Comparison with USGS gages at site using formula: $(\text{Modeled} - \text{Observed}) / \text{Observed}$

Flow Calibration – Whiteoak Bayou

	Heights	Cole Creek
Total Volume	13%	22%
10 th Percentile	~0%	-8%
90 th Percentile	13%	9%

Comparison with USGS gages at site using formula: $(\text{Modeled} - \text{Observed}) / \text{Observed}$
 Cole Creek volumes were corrected to account for WWTP at end of reach

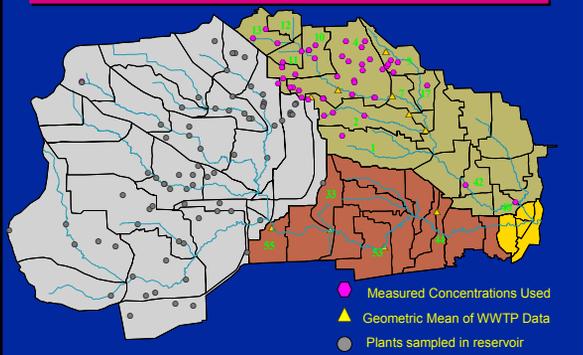
Water Quality Calibration Sites



Sources of EC

- 1 Non-point sources (runoff and sediment)
- 2 WWTP effluent (measured in Summer 2001)
- 3 Dry-weather discharges (measured in Summer 2001)
- 4 Reservoir contributions

WWTPs in the Model

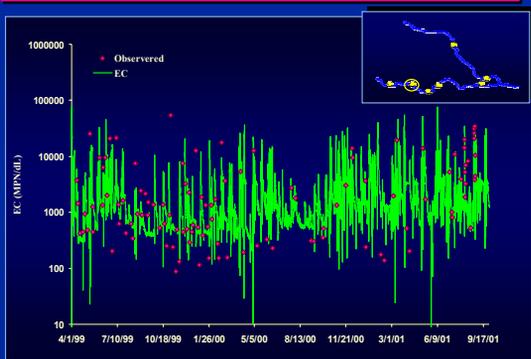


Comparison of point source and dry-weather inflow EC loadings

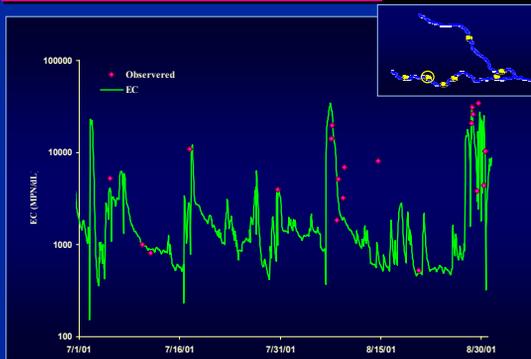
	Whiteoak		Buffalo	
	PS	DWI	PS	DWI
Field Data Flow*	9.5×10^3	2.2×10^2	6.0×10^3	1.8×10^2
Field Data Conc.	0.5-22,027	1- >240,920	0.5-295	1-173,287
Model Flow	7.5×10^3	2.2×10^2	6.5×10^3	1.8×10^2
Model Conc.	0.5-22,027	1- >240,920	5	1-173,287
Field Load	7.6×10^{14}	7.2×10^{13}	1.3×10^{12}	7.9×10^{13}
Model Load	6.6×10^{12}	7.2×10^{13}	2.2×10^{12}	7.9×10^{13}

DWI = dry-weather inflows; flows in MG/year; concentrations in MPN/100 mL; loads in MPN/year
 * Does not include plants above reservoirs

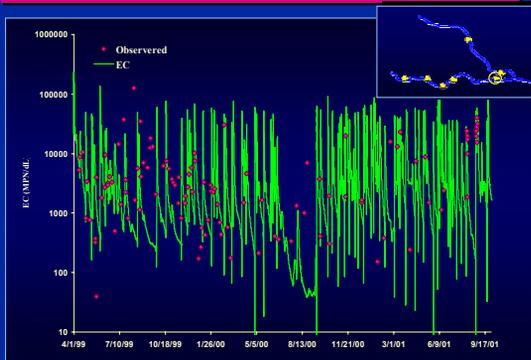
Buffalo Bayou WQ at West Belt



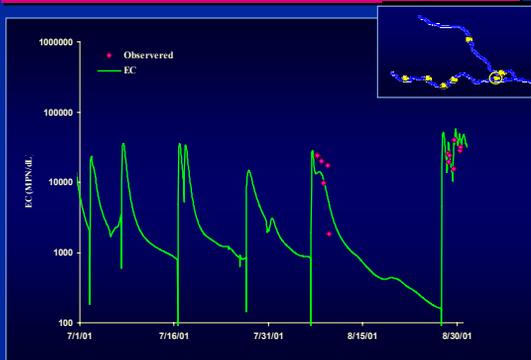
Buffalo Bayou WQ at West Belt - Summer



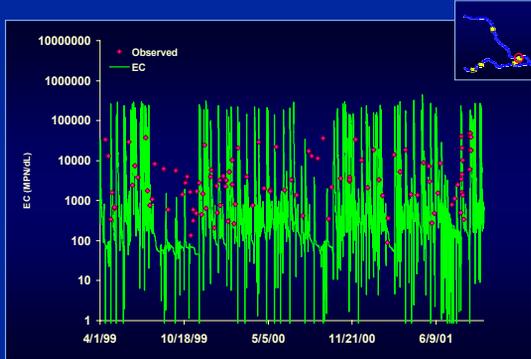
Buffalo Bayou WQ at Shepherd



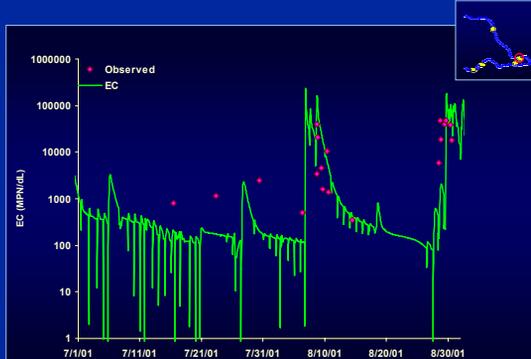
Buffalo Bayou WQ at Shepherd - Summer



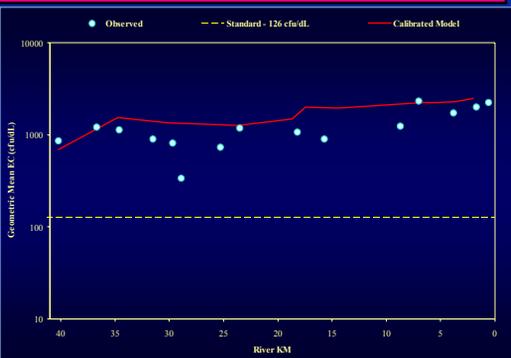
Whiteoak Bayou WQ @ Heights



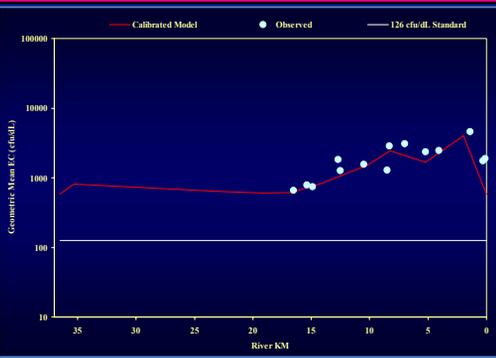
Whiteoak Bayou WQ @ Heights - Summer



Geomean EC – BB



Geomean EC – WOB



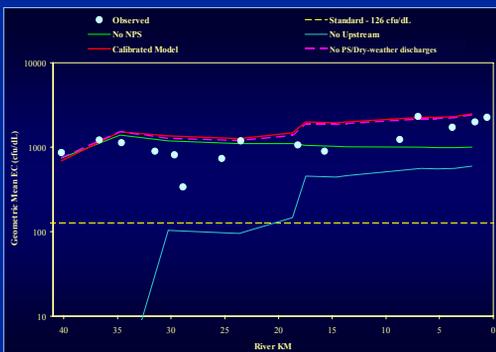
Load Allocation Scenarios

Eliminate WWTP and Dry Weather EC Discharges

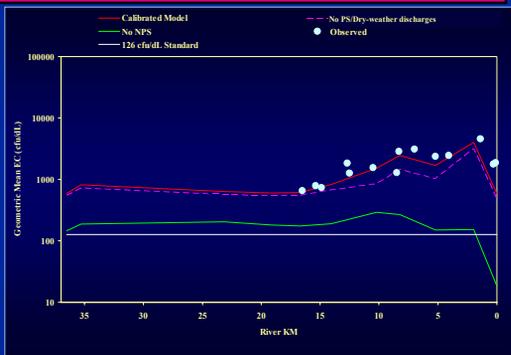
Eliminate Reservoir EC Load (Buffalo Bayou)

Eliminate all NPS (except sediment)

BB Allocation Scenarios



WO Allocation Scenarios



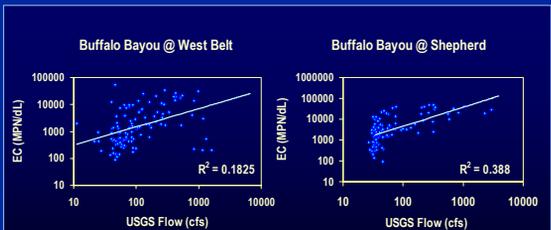
TMDL Load Allocation Analysis

$$LC = WLA + LA + MOS$$

- LC = loading capacity
- WLA = wasteload allocation (PS)
- LA = load allocation (NPS)
- MOS = margin of safety

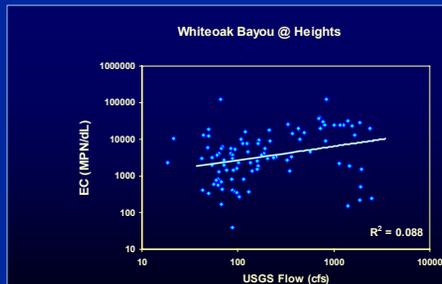
At what flow? Safe contact recreation based low flow?
Withdrawal issues? By-pass structure? BB redevelopment?

Flow vs EC in BB



EC data presented are converted from FC

Flow vs EC in WO

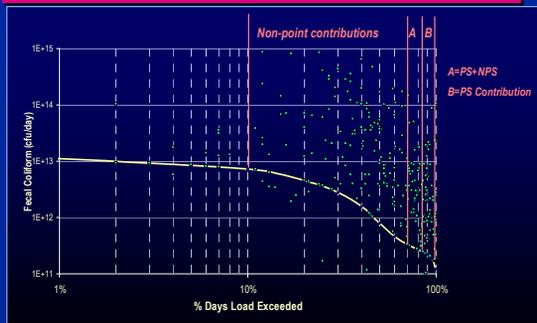


EC Data presented are converted from FC

The Kansas Methodology

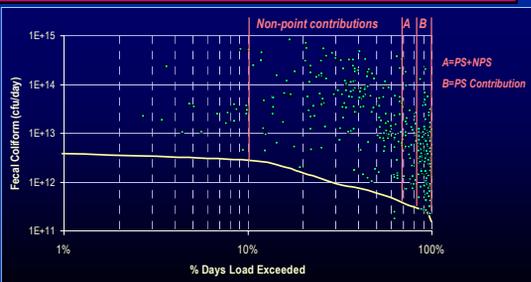
- Generate flow duration curve
- Draw Load Duration (TMDL) Curve by multiplying flow by WQ standard and by a conversion factor
- Convert quality samples to loads by multiplying the sample concentrations by the average daily flow
- Loads that plot above the curve in the flow regime exceeded 85-99% of the time are likely from PS
- The plotting above the curve over the range 10-70% exceedence likely correspond to NPS

Point vs Non-point Sources: TMDL Curve - BB @ Beltway 8



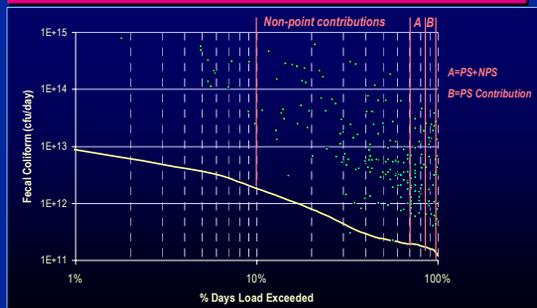
Bacteria data for 1992-1999 period
Curves prepared using Kansas TMDL Curve Methodology (KDHE, 1999)

Point vs Non-point Sources: TMDL Curve - BB @ Shepherd



Bacteria data for 1992-1999 period
Curves prepared using Kansas TMDL Curve Methodology (KDHE, 1999)

Point vs Non-point Sources: TMDL Curve - WO @ Heights



Bacteria data for 1992-1999 period
Curves prepared using Kansas TMDL Curve Methodology (KDHE, 1999)

On-going

- Identify appropriate flows for TMDL equation
- Assess relative PS and NPS loads using observed data
- Additional scenarios using models
- Estimate EC from solids and sediment
- BMPs

Important Considerations

- Drainage area above reservoirs
- Bacteria source tracking (human vs. non-human)
- Loads from birds