Anthropogenic Impacts to the Sediment Budget of the São Francisco River Navigation Channel using SWAT

2014 International SWAT Conference

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US Army Corps of Engineers
BUILDING STRONG®

CODEVASF-USACE Program Overview

- **CODEVASF** - Companhia de Desenvolvimento dos Vales do São Francisco e do Parnaíba
- **USACE** – United States Army Corps of Engineers
- 3 Year Partnership to address navigation obstacles in the São Francisco River Basin
- Initial Needs:
  - Understand Sediment Dynamics of the System – **SEDIMENT BUDGET**
  - Build a sediment yield and sediment transport model
  - Develop feasability studies for future navigation planning

São Francisco River Basin

- Basin Characteristics:
  - Eastern Brazil
  - Largest basin located entirely in Brazil
  - 640,000 sq. km (size of Texas)
  - 3000 km long (1/2 the Mississippi River)
  - Focus on navigation improvements in 400 km of the Middle São Francisco

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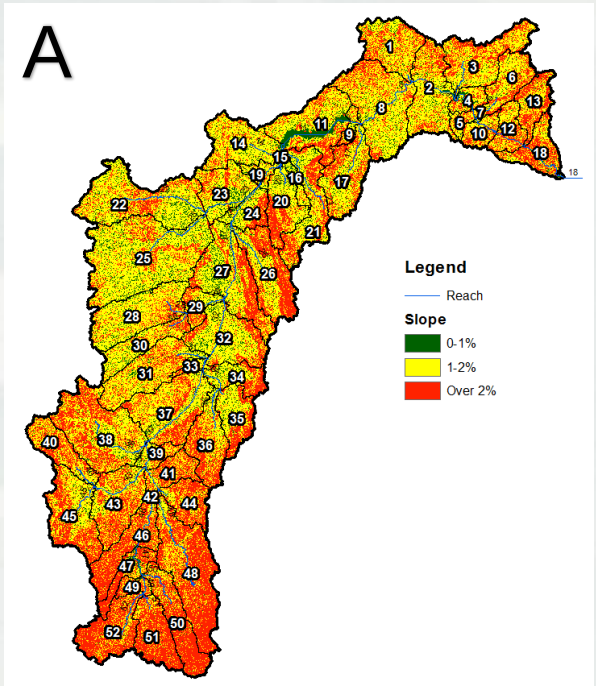
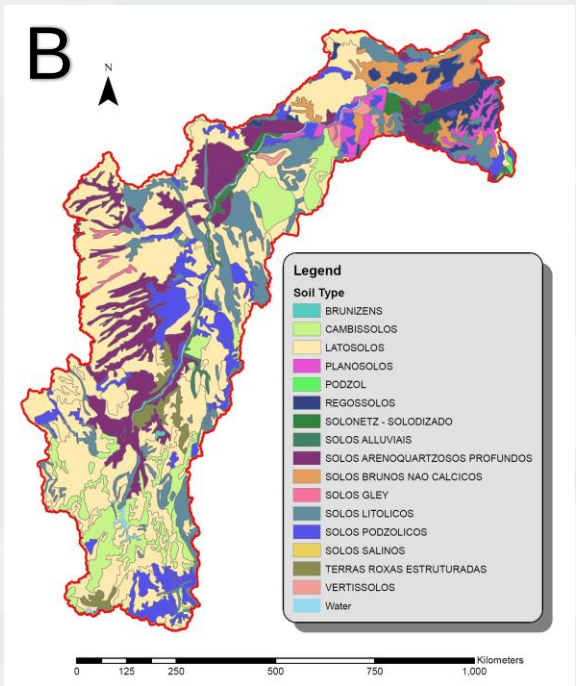
Navigation Obstacles in the São Francisco

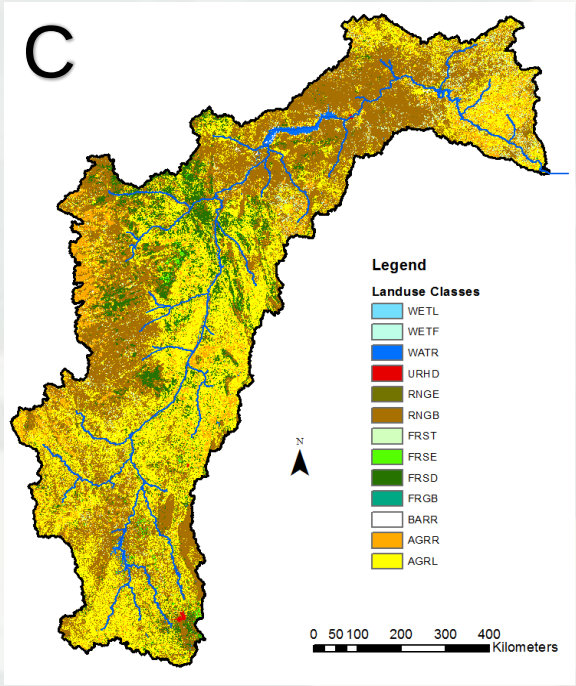
- Wide and shallow river
- Numerous shoals in navigation channel
- Very high sediment transport
- Numerous Islands

Sediment Yield Model Development: Hydrologic Response Units (HRUs)

- HRUs built from:
  - Slope (A) – ASTER 2013 30m DEM data
  - Soils (B) – Emprapa 1981 Soil Delination
  - Landuse (C) – European Space Agency Landuse Delineation (GlobCover 2005)
- Basin has a total of 3844 HRUs within 76 basins
- Climate data from the Climate System Forecast Reanalysis (CSFR)





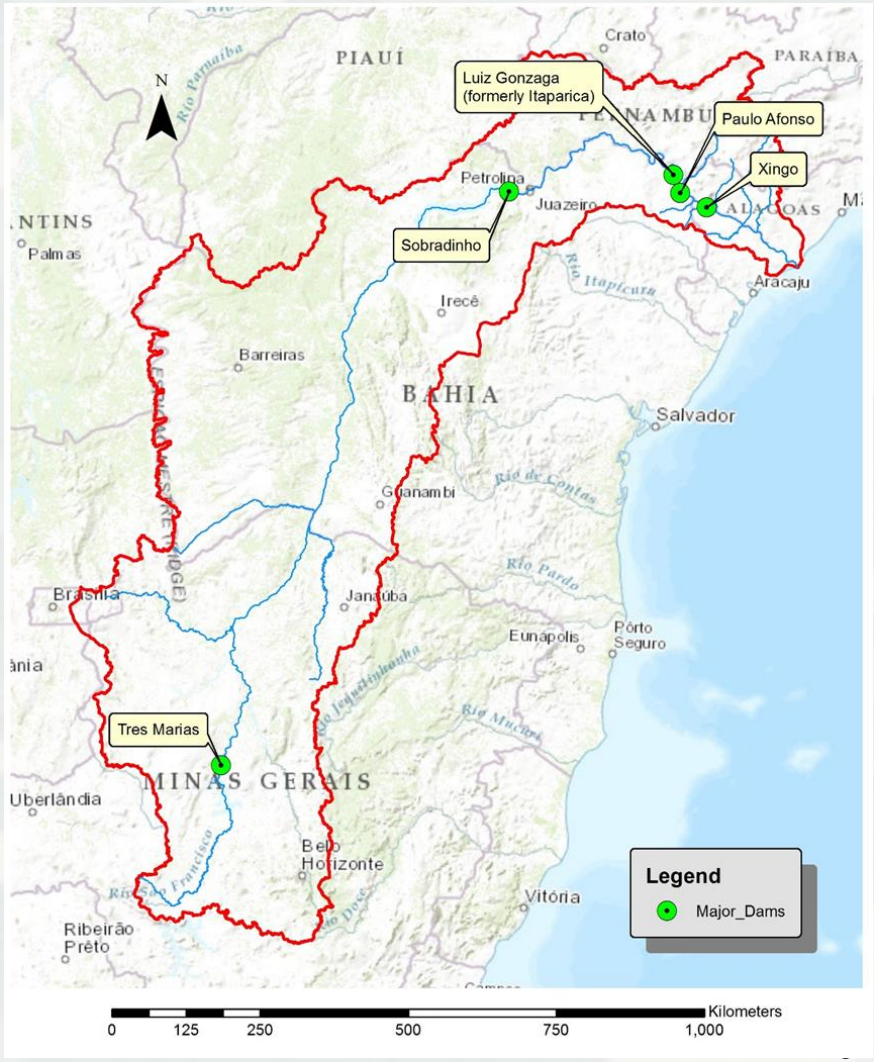


Sediment Yield Model Development: Reservoirs

- Reservoirs added (data from CHESF):
  - Três Marias
  - Sobradinho
  - Itaparica (Luiz Gonzaga)
  - Paulo Afonso
  - Xingó

SWAT ID	Reservoir Name	RES_ESA (ha)	RES_EVOL (10^4 m^3)	RES_PSA (ha)	RES_PVOL (10^4 m^3)	RES_VOL (10^4 m^3)
71	Três Marias	115556	2333333	104000	2100000	2100000
17	Sobradinho	468889	3788889	422000	3410000	3410000
8	Luiz Gonzaga	92222	1188889	83000	1070000	1070000
11	Paulo Afonso	11111	133333	10000	120000	120000
14	Xingó	6667	422222	6000	380000	380000

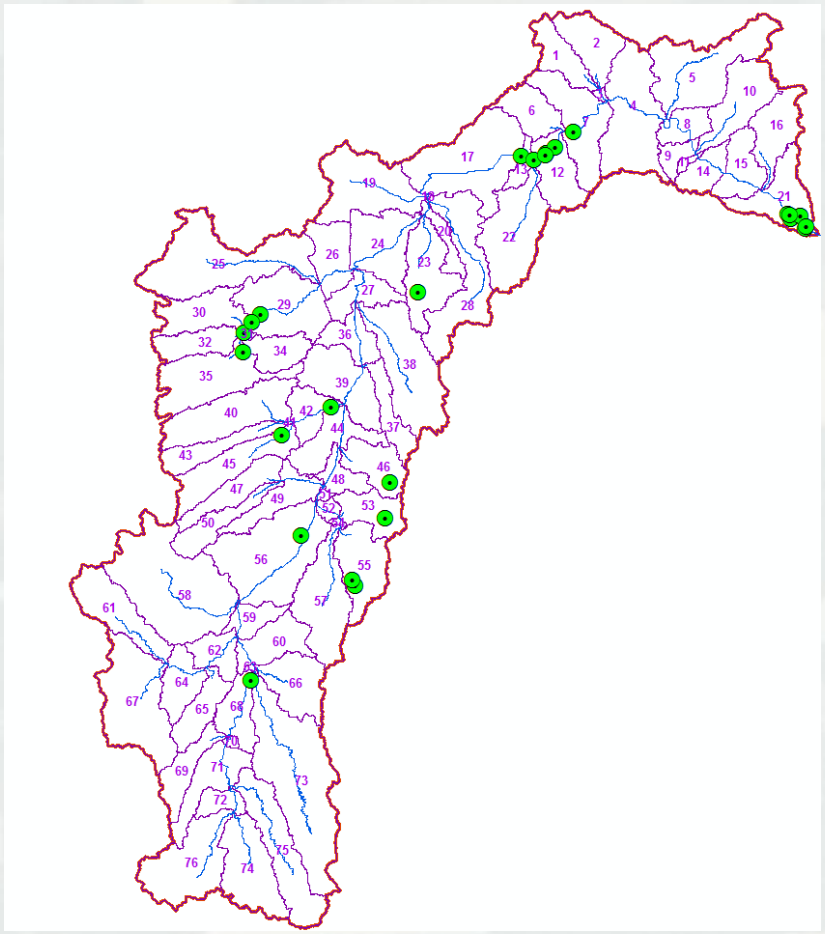
SWAT ID	Reservoir Name	RES_SED (mg/L)	RES_NSED (mg/L)	RES_D50 (µm)	RES_K (mm/hr)	EVRSV
71	Três Marias	100	450	10	0	0.6
17	Sobradinho	100	450	10	0	0.6
8	Luiz Gonzaga	100	450	10	0	0.6
11	Paulo Afonso	100	450	10	0	0.6
14	Xingó	100	450	10	0	0.6



Sediment Yield Model Development: Irrigation

- Irrigation Canal added:
  - 26 Total Irrigation Canals
  - 16 Basins

Name	Coordinates		Name of Source	Source Type	Intake Type	Permitted Flow m^3/h	SWAT Basin
	Latitude	Longitude					
Gorutuba	15º 49' 55'' S	43º 15' 46'' W	Gorutuba	Dam	Gravity	8762	55
Jaíba	15º 5' 24.088'' S	44º 5' 24.088'' W	São Francisco	River	Pump	53529	56
Lagoa Grande	15º 44'55'' S	43º18'36''W	Gorutuba	Dam	Pump	8740	55
Pirapora	17º 14' 56'' S	44º 51' 14'' W	São Francisco	River	Pump	3750	68
Barreiras do Norte	12º 4' 47.509'' S	44º 57'' 59.326'' W	Grande	River	Pump	12642	31
Ceraíma	14º 17' 23'' S	42º 44' 8'' W	Carnaíba de Dentro	Dam	Gravity	539	46
Estreito	14º 49' 35'' S	42º 48' 27'' W	Verde Pequeno	Dam	Gravity	4669	53
Formoso A	13º 11' 7'' S	43º 38' 37'' W	Corrente	River	Pump	47160	42
Miroros	11º 27' 34'' S	42º 20' 34'' W	Verde	Dam	Pump	3110	23
Nupeba	11º 48' 35'' S	44º 43' 0'' W	Grande	River	Pump	14196	29
Piloto Formoso	13º 36' 16'' S	44º 23' 45'' W	Formoso	River	Pump	1620	45
Riacho Grande	11º 55' 28'' S	44º 50' 48'' W	Grande	River	Pump	8042	29
São Desidério	12º 21' 38'' S	44º 58' 20'' W	São Desiderio	Dam	Gravity	4700	35
Bebedouro	9º 22' 44.775'' S	40º 26' 38.103'' W	São Francisco	River	Pump	13320	12
Nilo Coelho	9º 25' 36.603'' S	40º 49' 20.852'' W	São Francisco	River	Pump	83520	13
Betume	10º 25' 4'' S	36º 33' 34.487'' W	São Francisco	River	Pump	7167	21
Cotinguiba-Pindoba	10º 16' 30'' S	36º 46' 55'' W	São Francisco	River	Pump	6939	21
Propria	10º 12' 18.605'' S	36º 50' 4.445'' W	São Francisco	River	Pump	5775	21
Boacica	10º 14' 04'' S	36º 38' 25'' W	São Francisco	River	Pump	9345	21
Itiúba	10º 13' 13,2'' S	36º 47 53.4'' W	São Francisco	River	Pump	3373	21
Marituba	10º 23' 38'' S	36º 33 8'' W	São Francisco	River	Pump	4817	21
Curaçá	9º 3' 44'' S	40º 2' 52'' W	São Francisco	River	Pump	19675	7
Mandacaru	9º 23' 3'' S	40º 26' 32'' W	São Francisco	River	Pump	5200	12
Maniçoba	9º 17' 358'' S	40º 18' 57'' W	São Francisco	River	Pump	23160	12
Salitre 1	9º 28' 52.644'' S	40º 37' 36.879'' W	São Francisco	River	Pump	25200	22
Tourão	9º 24' 26.558'' S	40º 27' 31.108'' W	São Francisco	River	Pump	47736	12



Sediment Yield Model: Hydrology Calibration

- 18 Parameters adjusted to achieve calibration:

Hydrology Calibration Parameters				
Parameter	**Table**	**Name**	**Default**	**Value Used**
CH_W2 (m)	.rte	Main channel width	Varies	Varies
ALPHA_BF (days^{-1})	.gw	Baseflow alpha days	0.048	0.05
CH_W1 (m)	.sub	Tributary channel width	Varies	10
CH_N2	.rte	Manning's "n" value for main channels	0.014	0.03
CH_D (m)	.rte	Channel depth	Varies	10% of channel width, with maximum of 10 m
CN2	.mgt	Runoff curve number	Varies	Default
SOL_K (mm/hr)	.sol	Saturated hydraulic conductivity	Varies	Default / 5
CH_K2 (mm/hr)	.rte	Hydraulic conductivity in main channel	0	5
CH_K1 (mm/hr)	.sub	Hydraulic conductivity in tributaries	0	5
HRU_SLP	.hru	Average slope steepness of HRU	Varies	Default
SLSUBBSN (m)	.hru	Average slope length	50	90
OV_N	.hru	Manning's "n" value of overland flow	0.08	0.08
RCHRG_DP	.gw	Deep aquifer percolation fraction	0.05	0.6
SURLAG	.bsn	Surface runoff lag time	4	0.05
GWQMN (mm)	.gw	Depth of water in shallow aquifer for return flow	0	0
GW_REVAP	.gw	Groundwater revap coefficient	0.02	0.02
REVAPMN (mm)	.gw	Depth of water in shallow aquifer for revap	1	100
GW_DELAY (days)	.gw	Groundwater Delay	31	0

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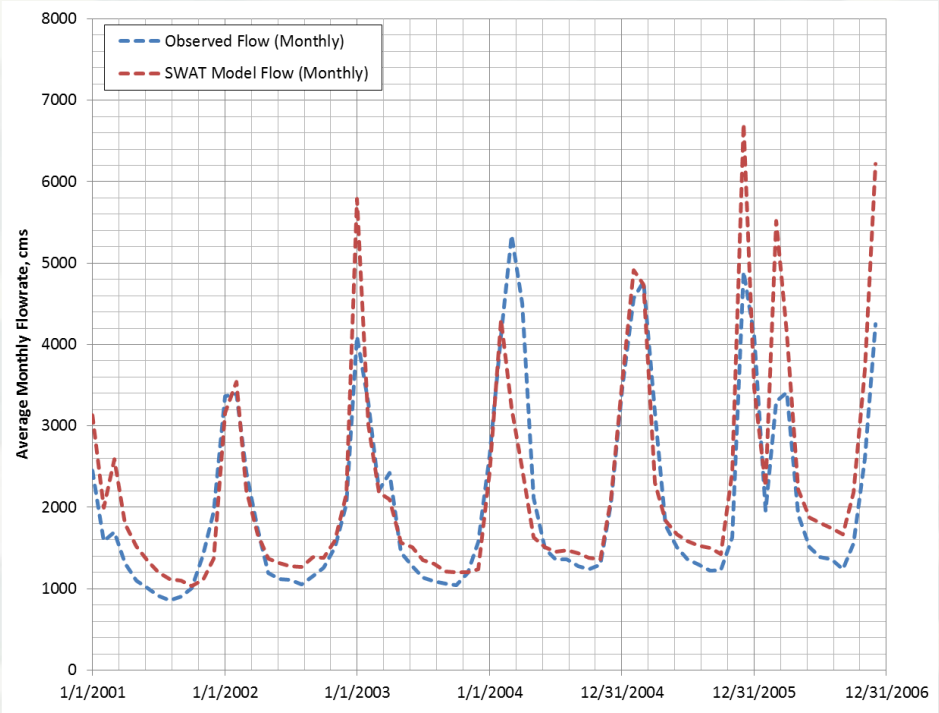
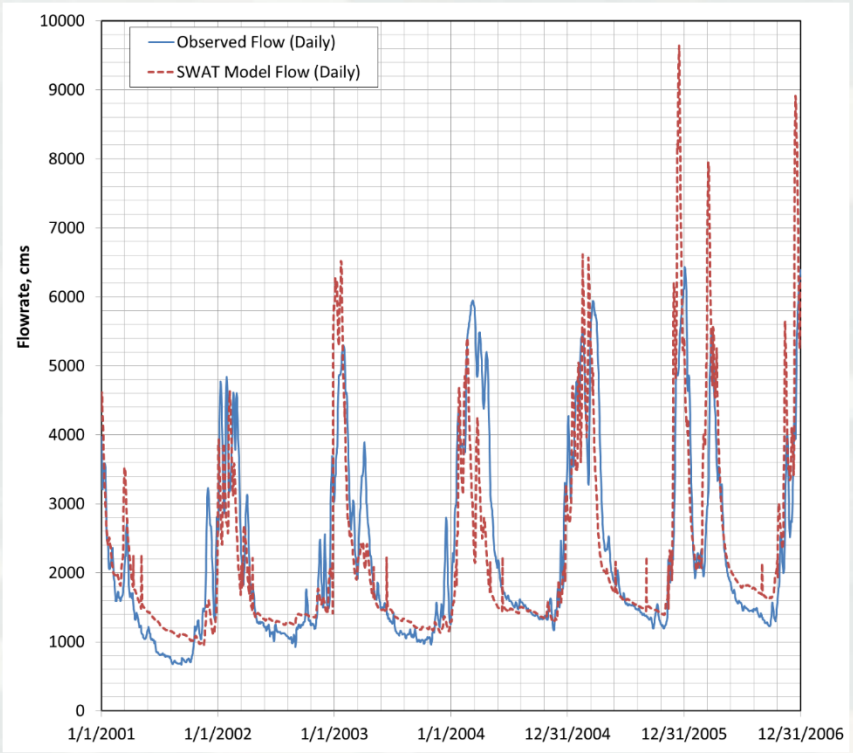
Sediment Yield Model Hydrology Calibration

- Morpara Gage
- Monthy Hydrology
- NSE = 0.66 (good)



- Morpara Gage
- Daily Hydrology
- NSE = 0.56 (good)



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Sediment Yield Model
Hydrology Calibration

- 10 gages used for Calibration (Each of the Major Tributaries)
- 7 gages used for Validation (Along the São Francisco River)
  - 3 Gages – Very Good
  - 6 Gages – Good
  - 8 Gages – Satisfactory

ANA Name	Gage	SWAT Basin	Type	NSE	Description
Rio Pará	40330000	74	Calibration	0.66	Good
Rio Paraopeba	40850000	75	Calibration	0.72	Good
Rio das Velhas	41818000	73	Calibration	0.63	Satisfactory
Rio Jequitaí	42145498	66	Calibration	0.67	Good
Rio Paracatu	42980000	62	Calibration	0.61	Satisfactory
Rio Urucuia	43980002	58	Calibration	0.57	Satisfactory
Rio Verde Grande	44670000	57	Calibration	0.6	Satisfactory
Rio Carinhanha	45260000	49	Calibration	0.58	Satisfactory
Rio Corrente	45960001	42	Calibration	0.67	Good
Rio Grande	45965000	26	Calibration	0.52	Satisfactory
Rio São Francisco upstream of Pará	40100000	76	Validation	0.51	Satisfactory
Rio São Francisco at Manteiga	42210000	60	Validation	0.73	Good
Rio São Francisco at Manga	44500000	56	Validation	0.75	Very Good
Rio São Francisco at Bom Jesus de Lapa	45480000	44	Validation	0.76	Very Good
Rio São Francisco at Morpara	46360000	27	Validation	0.66	Good
Rio São Francisco at Juazeiro	48015000	12	Validation	0.88	Very Good
Rio São Francisco at Ibó	48590000	4	Validation	0.57	Satisfactory

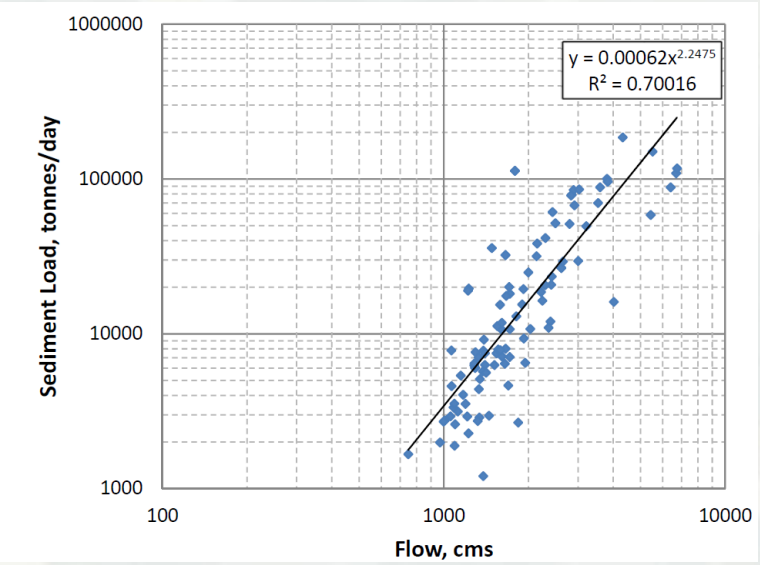
Sediment Yield Model
Sediment Calibration

- 12 Parameters adjusted to achieve calibration:

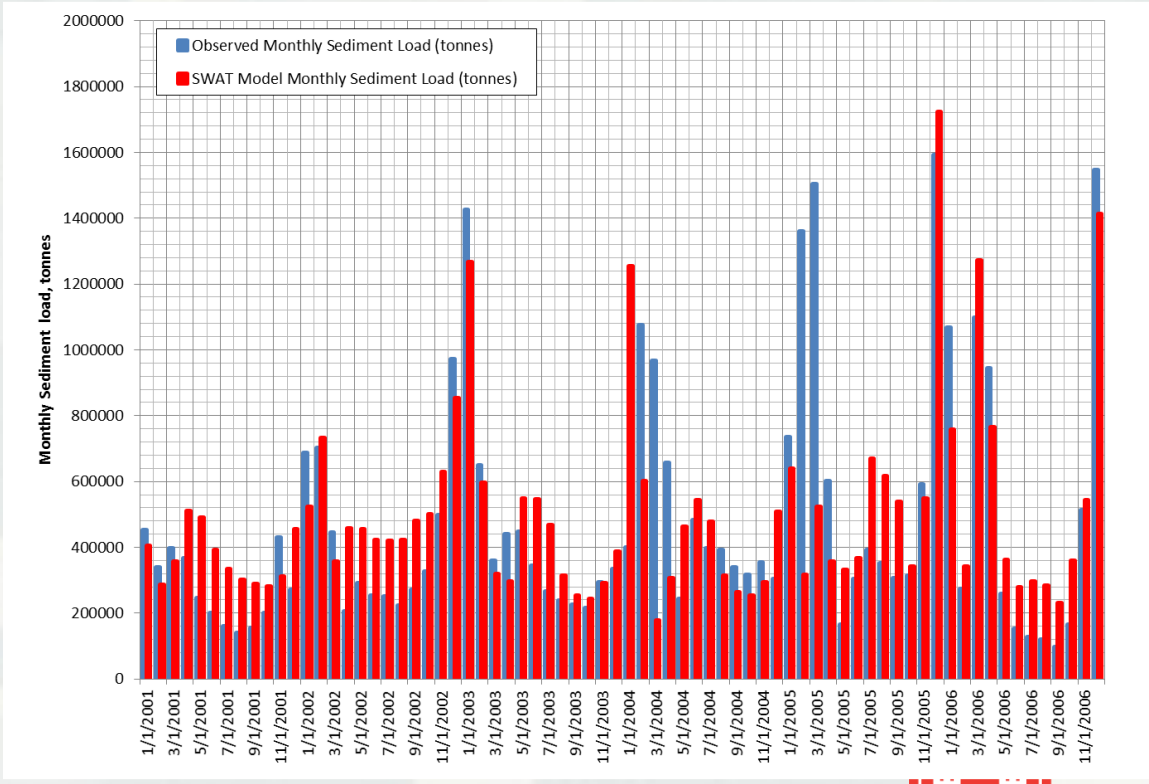
Sediment Calibration Parameters				
Parameter	**Table**	**Name**	**Default**	**Value Used**
CH_WDR (m/m)	.rte	Channel width/depth ratio	Varies	Initial Width/Depth Ratio - 1
CH_COV1	.rte	Channel erodability factor	0	0.6
USLE_P	.mgt	Universal Soil Loss Equation Support Practice Factor	1	0.15
LAT_SED (mg/l)	.hru	Sediment Concentration in lateral flow	0	0
CH_BNK_KD (cm^3/N-s)	.rte	Erodibility of Channel Bank Material	0	0.1
CH_BNK_D50 (µm)	.rte	Median particle size of bank material	0	500
CH_BED_D50 (µm)	.rte	Median particle size of bank material	0	500
CH_BNK_TC (N/m^2)	.rte	Critical Shear Stress of Channel Bank	0	0.2
CH_BED_TC (N/m^2)	.rte	Critical Shear Stress of Channel Bank	0	0.08
CH_ERODMO1-12	.rte	Erodibility factor by month	0	1
CH_BED_KD	.rte	Erodibility of Channel Bed Material	0	1
CH_EQN	.rte	Sediment Transport Equation	0	1
RES_SED (mg/L)	.res	Initial Sediment Concentration in Reservoir	4000	1
RES_NSED (mg/L)	.res	Normal Sediment Concentration in Reservoir	4000	1

Sediment Yield Model
Sediment Calibration

- Sediment Rating Curve at Morpara Gage converted to daily sediment loads, then aggregated monthly



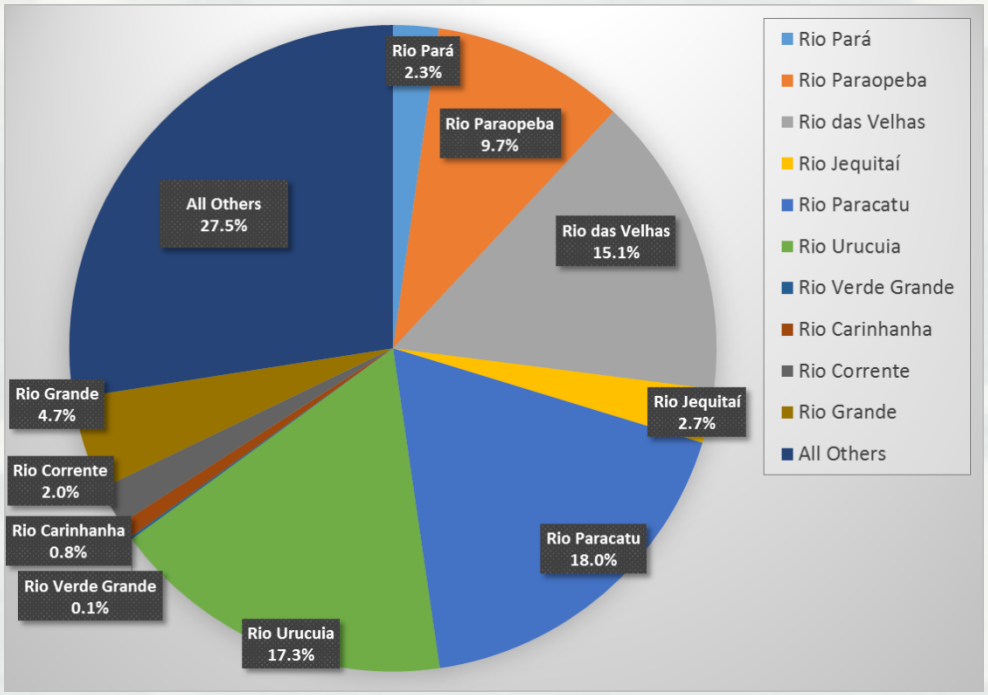
- Morpara Gage - Monthy Sediment Loads
- PBIAS = -12.6 (Very Good)

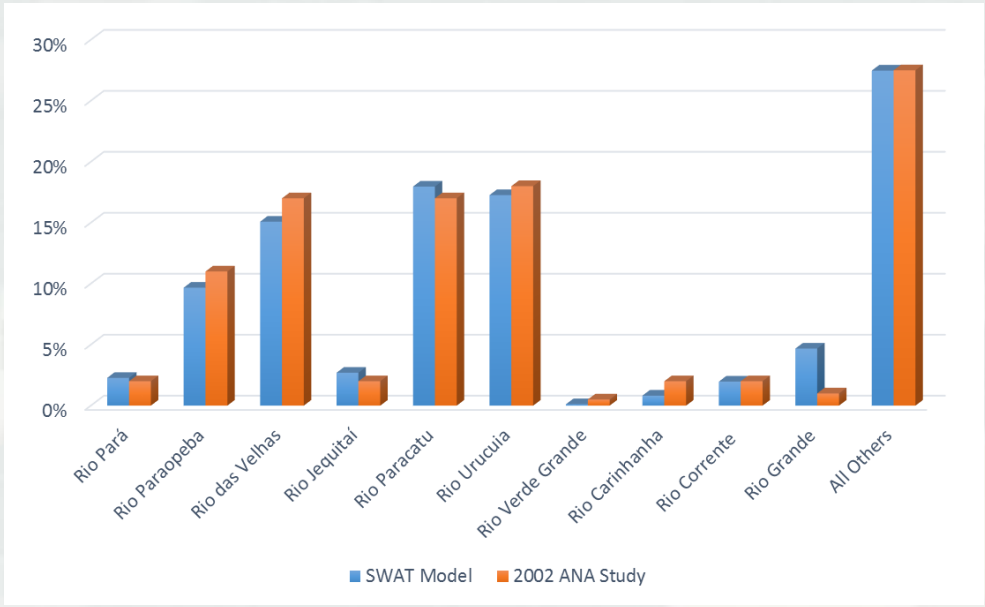


Sediment Yield Model
Sediment Calibration

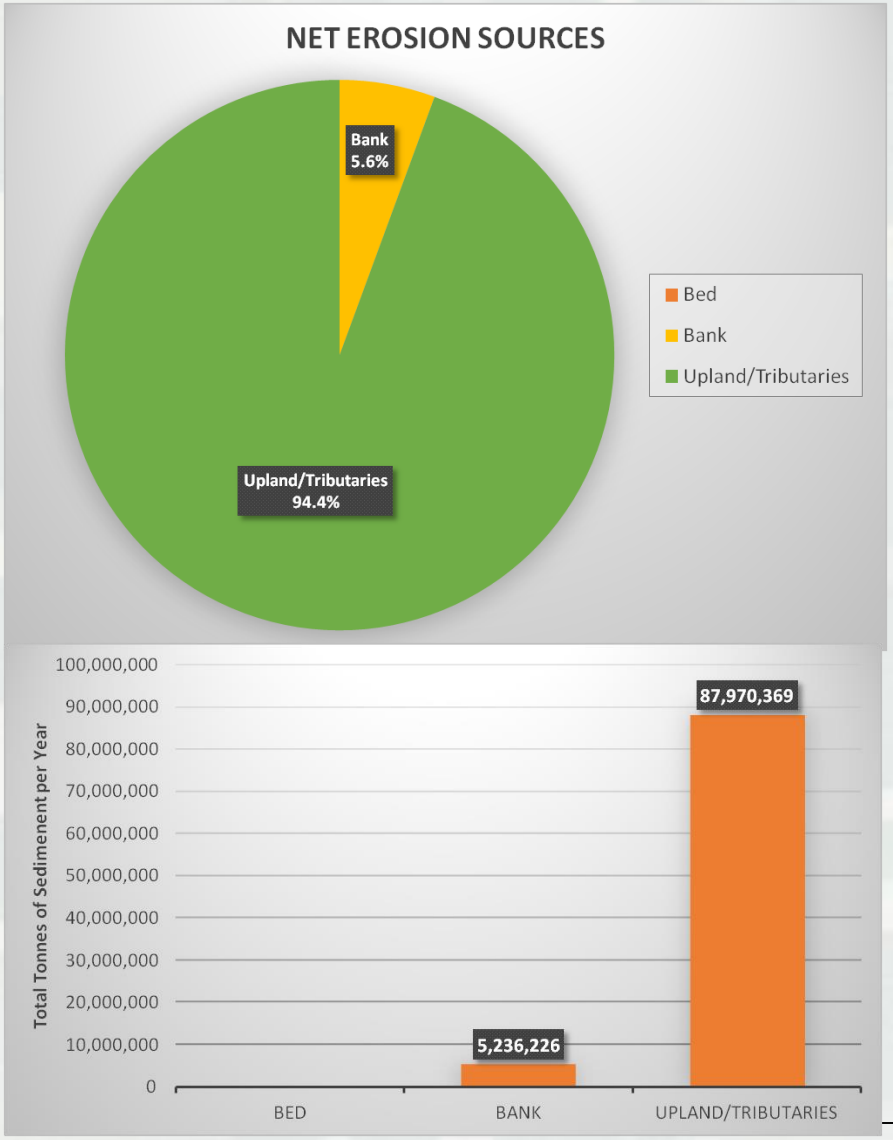
- Tributary Sediment Loads
  - Compared with ANA & CODEVASF, 2002 Study
  - (Anãlise Multitemporal da Dinâmica de Alteração da Conformação do Leito do Rio São Francisco – Trecho Médio)

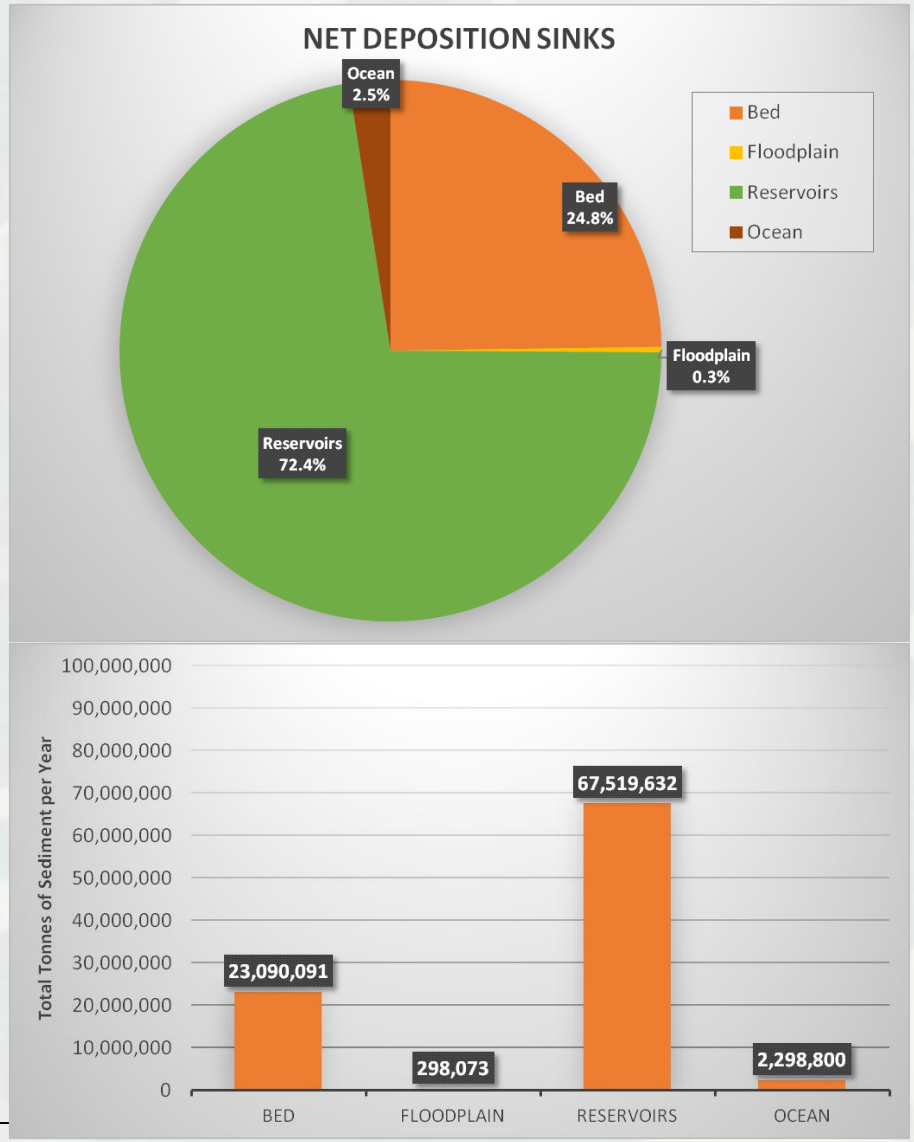
Tributary	SWAT Model	2002 ANA Study
Rio Pará	2.27%	2.00%
Rio Paraopeba	9.67%	11.00%
Rio das Velhas	15.08%	17.00%
Rio Jequitaí	2.70%	2.00%
Rio Paracatu	17.96%	17.00%
Rio Urucuia	17.26%	18.00%
Rio Verde Grande	0.11%	0.50%
Rio Carinhanha	0.82%	2.00%
Rio Corrente	1.97%	2.00%
Rio Grande	4.68%	1.00%
All Others	27.47%	27.50%
TOTAL	100.00%	100.00%





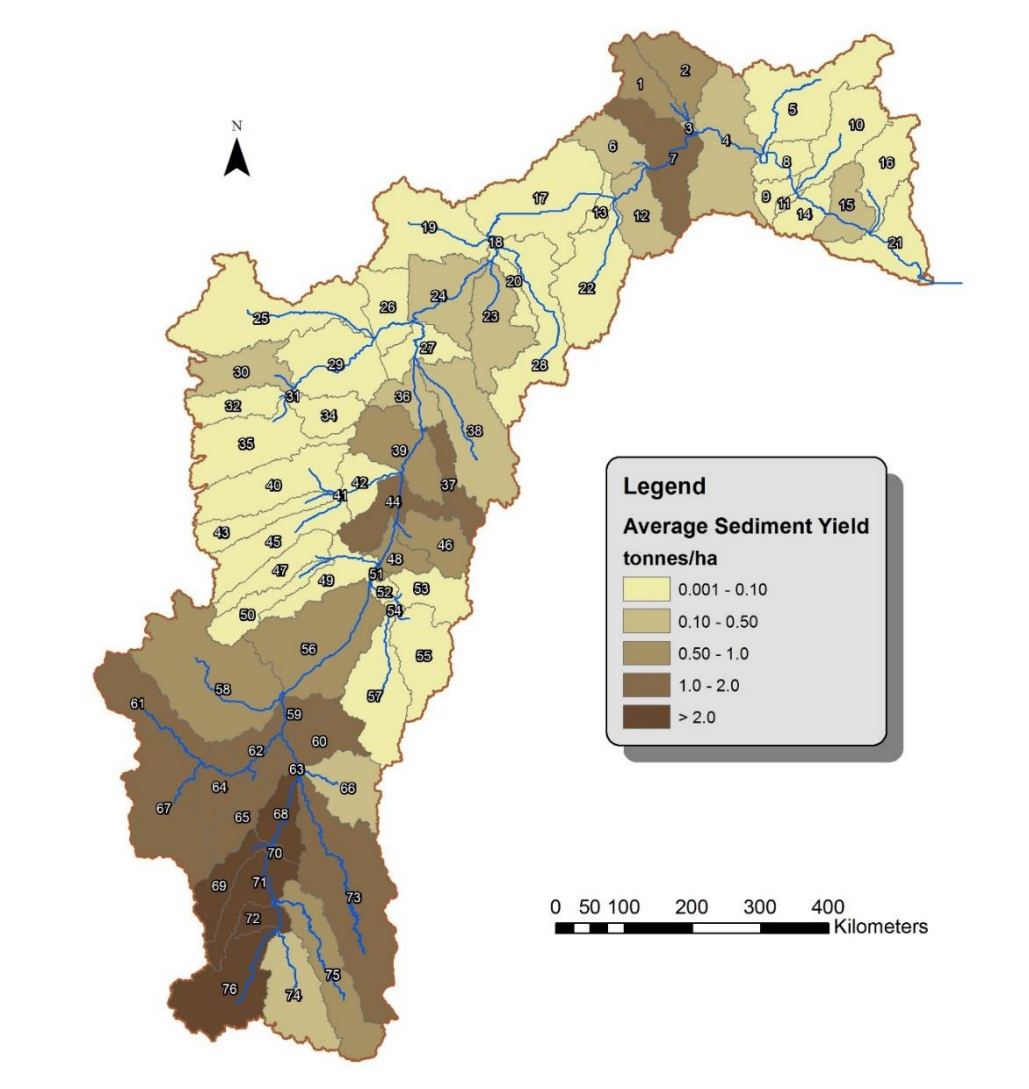
Sediment Yield Model Output – Sediment Budget





Sediment Yield Model Output - Sediment

- Distribution of Sediment Yield
  - Significant Yield (> 2.0 tonnes/hectare per year) in the Upper
  - Very low (< 0.1 tonnes/hectare per year) in Western Bahia, and other portions of the Middle, Lower Middle, and Lower São Francisco



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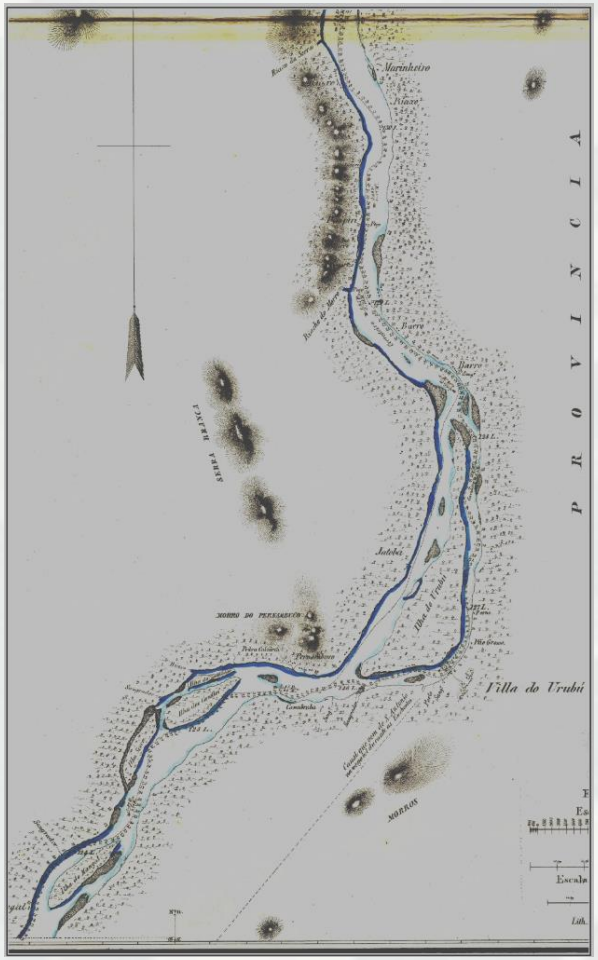
Comparison of Historic Conditions

- Updated Historic River Widths
- Converted Landuse to Cerrado & Caatinga (& Atlantic Forest)
- Removed Dams
- Removed Irrigation



Halfeld Map, 1852

LANDSAT, 1999

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Comparison of Historic Conditions

Erosion (Sources)	Pre-European Settlement Loads (tonnes/year)	Current Condition Sediment Loads (tonnes/year)	Change, %
Bed	27,895,898	50,700,317	82%
Bank	755,943	5,236,226	593%
Upland / Tributaries	31,172,709	87,970,369	182%
Deposition (Sinks)	**Pre-European Settlement Loads (tonnes/year)**	**Current Condition Sediment Loads (tonnes/year)**	**Change, %**
Bed	29,134,816	73,790,408	153%
Floodplains	38,045	298,073	683%
Reservoirs	0	67,519,632	∞
Oceans	3,911,667	2,298,800	-41%

- **Pre-European Settlement Waterway:** 1.25 million tonnes per year deposition
- **Current Conditions Waterway:** 23 million tonnes per year deposition

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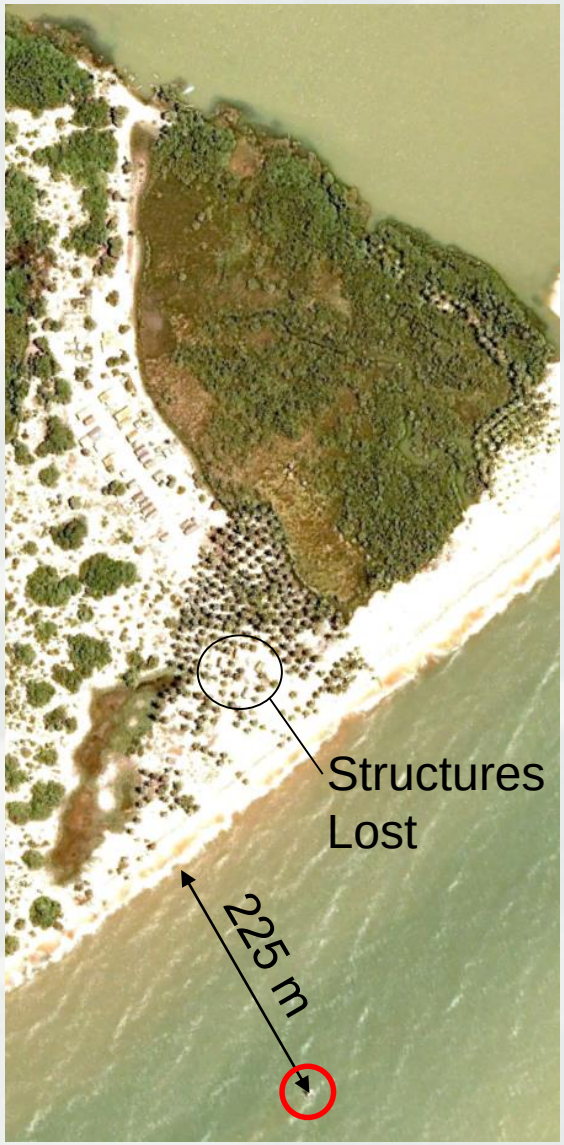
Comparison of Historic Conditions



2004 Aerial

2011 Aerial

- 3.9 million tonnes delievered to ocean (historic) compared to 2.3 million (current)
- Coastal Erosion: 175 meters of erosion from 2004 to 2011 at the lighthouse
- Numerous Structures and coconut farming lost at Cabeça Village

Future Watershed Planning Conditions

- Inflows to the Basin at Headwaters:
  - Bacia do Rio Grande
  - Bacia do Rio Paranaíba
  - Bacia do Rio São Marcos
- Proposed Dams
  - Velhas (1 dam)
  - Paracatu (3 dams)
  - Urucuia (1 dam)
- Irrigation in the Lower
  - 12 proposed systems
- Potential landuse changes (more agriculture)

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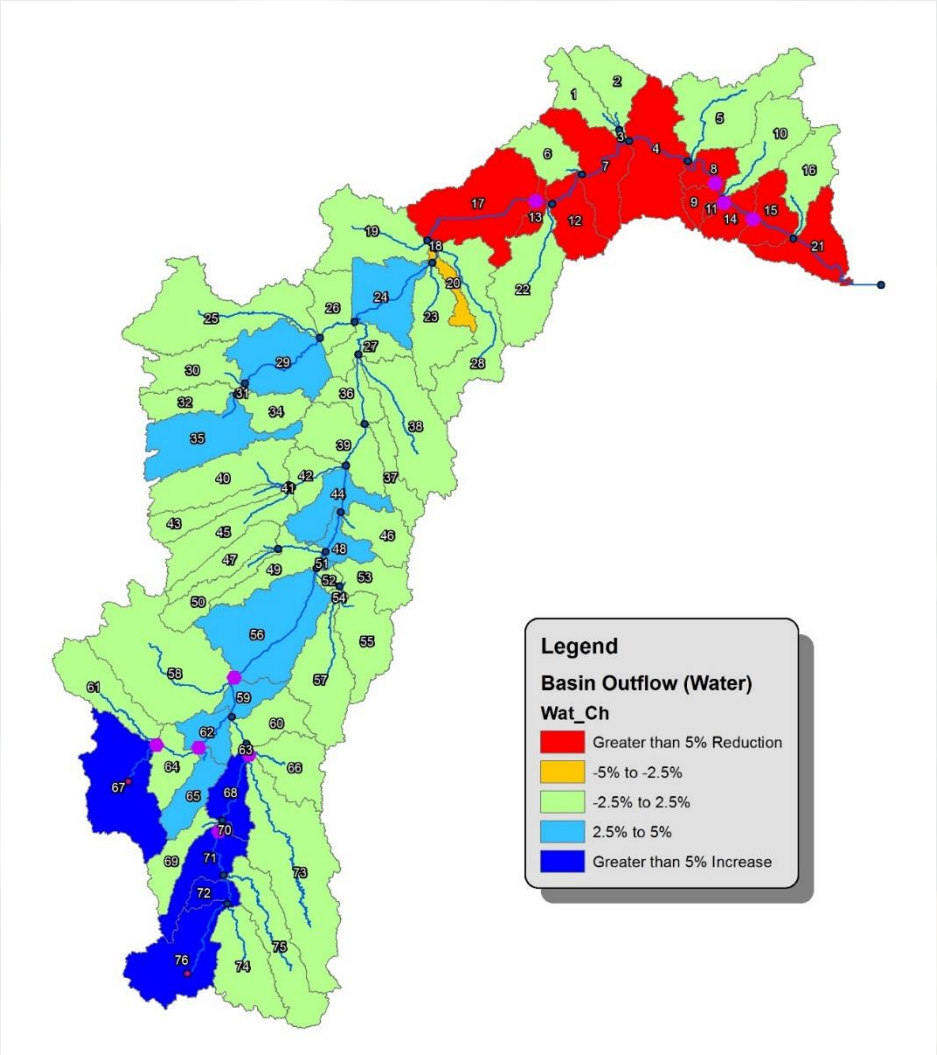
Future Watershed Planning Conditions Hydrology

- Significant Increased Flows in the Headwaters
- Increased flows through the navigation channel
- Significant decreased in flows in the Middle Lower and Lower



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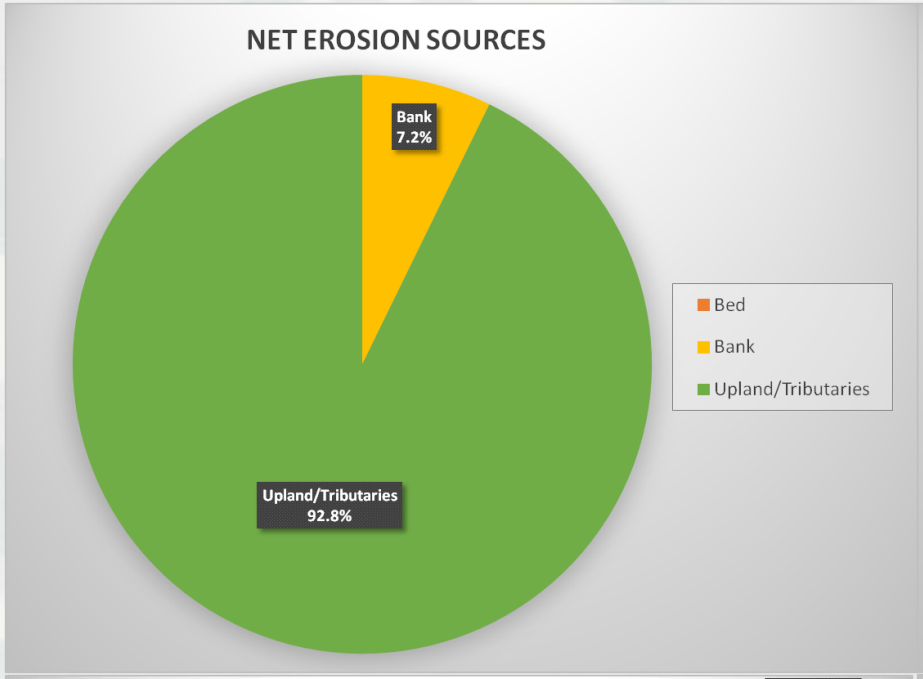
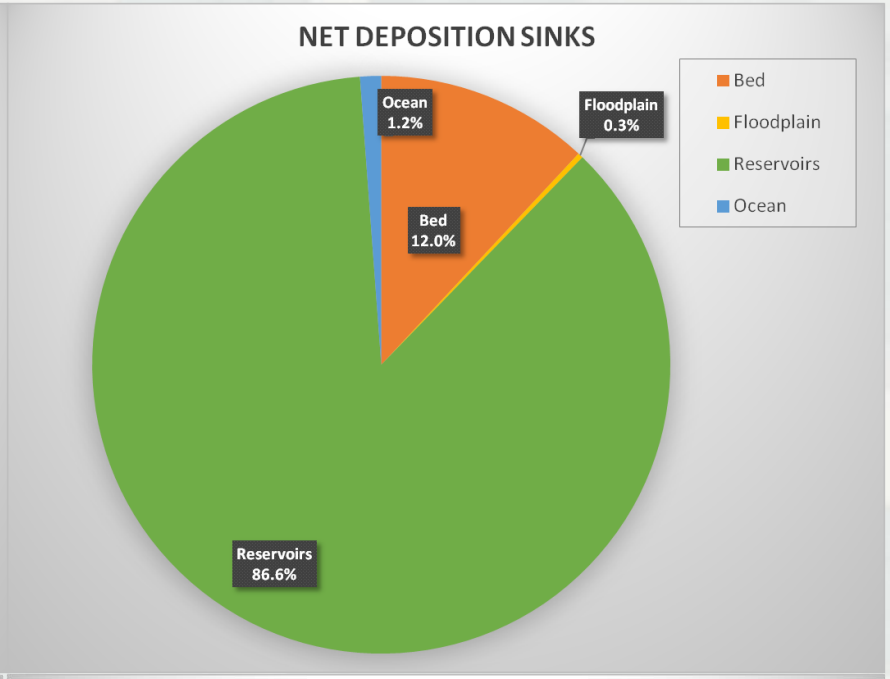
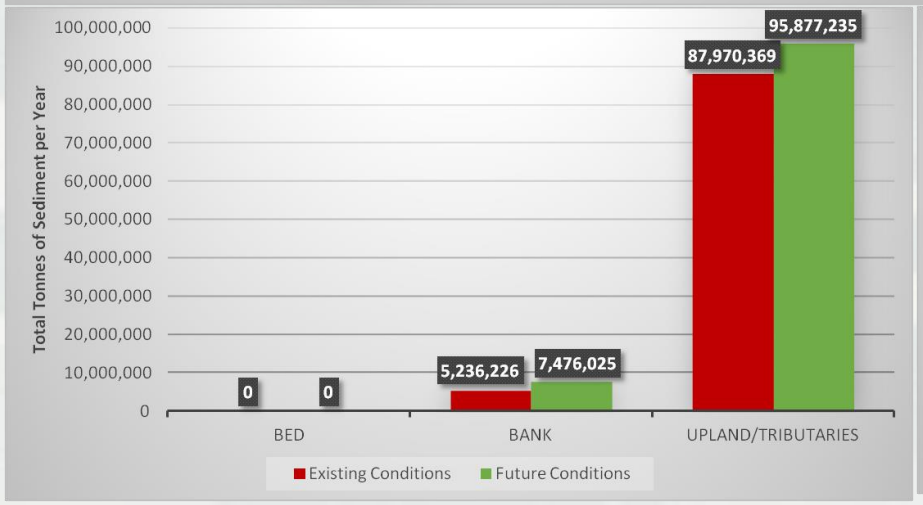
Comparison of Future Conditions







SWAT Model Conclusions / Recommendations

- Small component of existing and future sediment budget is due to Bank Erosion (~6%). 94% of the sediments causing shoals are due to overland flow or small tributary inflows.
- Existing navigation channel is experiencing aggradation of the bed. Historically quase-equilibrium - 1.25 million tonnes of aggradation - compared to current 23 million tonnes of aggradation.
- 41% reduction in sediment delivery to the Atlantic Ocean since historic conditions (3.9 million tonnes per year Pre-European settlement, compared to 2.3 million tonnes per year currently)
- Future landuse scenarios will continue to have an aggrading bed, but a 39% lower rate. Primarily due to the construction of proposed dams.
- Output of the sediment yield model was used as the input into a sediment transport model

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Perguntas? Discussão?
Muito Obrigado!

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