Innovations in Urban Applications of SWAT

Roger H. Glick, P.E., Ph.D.
Jaehak Jeong, P.E., Ph.D.
Leila Gosselink, P.E.

Texas AgriLife Research, Blacklands Center
Watershed Protection Department City of Austin, Texas

Presented at

2017 International SWAT Conference

Warsaw, Poland
June 28-30, 2017

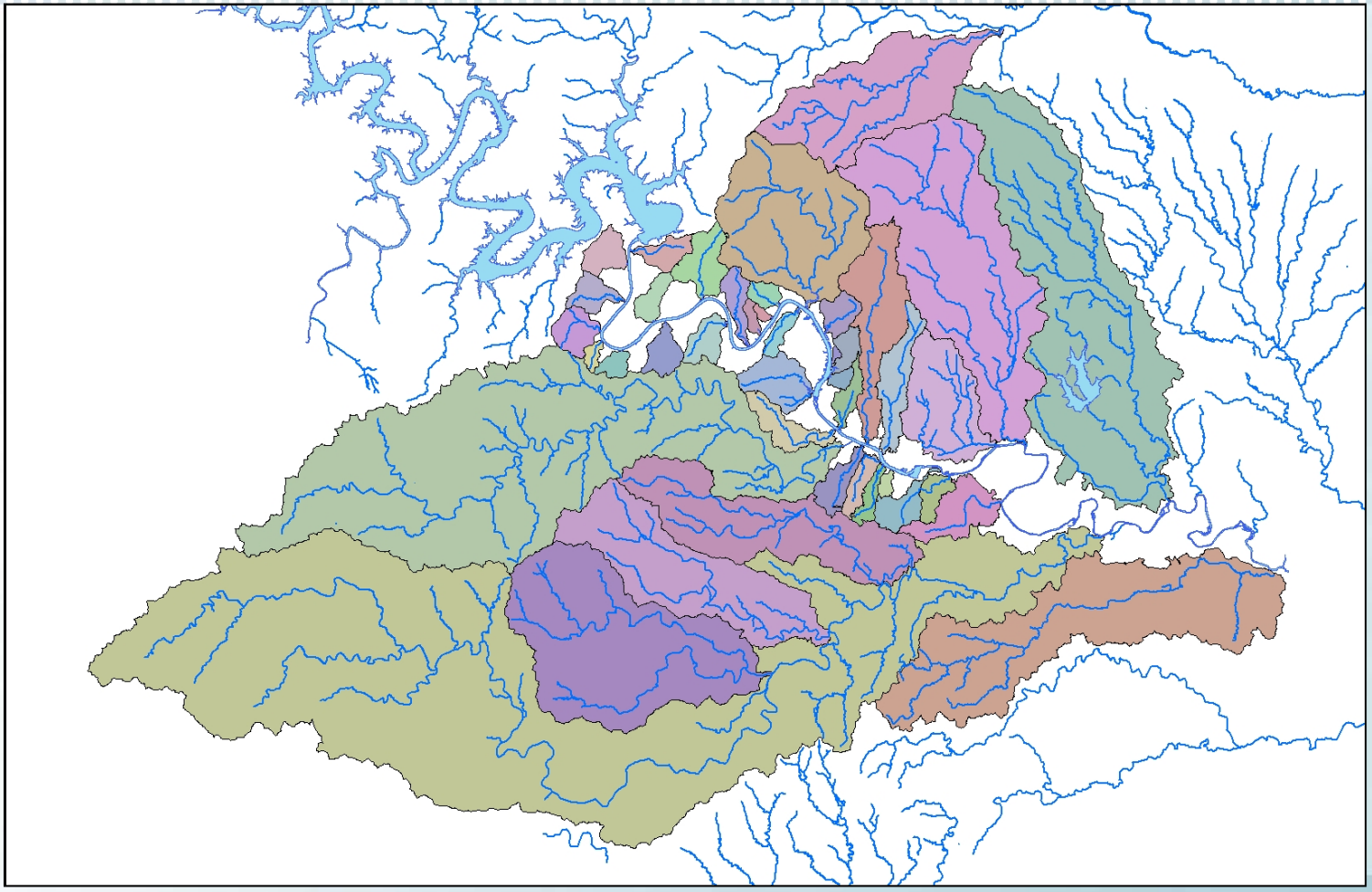
TEXAS A&M AGRILIFE RESEARCH

City of Austin WATERSHED PROTECTION

Project Background

- WPD has three missions flood, erosion and water quality
- Urban watershed modeling focused on flooding, primarily event based models
- Poor models for long-term simulations
- No tools to evaluate long-term impacts of development or regulations on erosion or water quality

Project Area – Austin, Texas



Needed Tools

- Model capable of continuous long-term simulations.
- Subhourly time step
- Surface/groundwater interactions
- Common urban stormwater controls
- Capable of changing land uses
- Framework to evaluate impacts on erosion and water quality.

SWAT Improvements

- Runoff and routing at subhourly time-step
- Sediment processes at subhourly time-step
- Urban stormwater control routines
  - Reach level – detention and wet ponds
  - Subbasin level – sedimentation, filtration and retention/irrigation
  - HRU level – cisterns, green roofs, porous pavement, and rain gardens

Evaluation Framework Development

- Erosion – average annual excess shear
- Flooding – change in peak frequency
- Water Quality – compare hydrologic metrics to undeveloped condition
  - Focus on hydrology for overall stream health
  - Baseflow duration
  - Hydrograph response to rainfall

Erosion Evaluation

Shear and critical shear were computed by:

$$\tau = \gamma_w \bullet D_H \bullet S_w$$

$$\tau_c = \theta_c \left(S_g - 1\right) \bullet \gamma_W \bullet d_{50}$$

where,

γ_w = density of water
D_H = depth of water
S_w = channel slope
S_g = specific gravity of soil, 2.65
d_{50} = median particle diameter, mm
θ_c = critical Shield's parameter, 0.047

$$ESP = \sum \left(\tau - \tau_c\right) \bullet V \quad \text{for all } \tau > \tau_c$$

Flood Evaluation

- Flow peak return periods
  - Computed peak return based on measured rainfall and simulated period of record.
  - Frequent return period analyses
- Design rainfall peaks
  - Insert 24-hr design rainfall (2, 5, 10, 25, 50 and 100-yr) into simulation rainfall file
  - Long return period

Water Quality Evaluation

- Compare hydrologic metrics affecting stream flow (wet v. dry)
- Compare hydrologic metrics affecting flow variability

Water Quality Evaluation

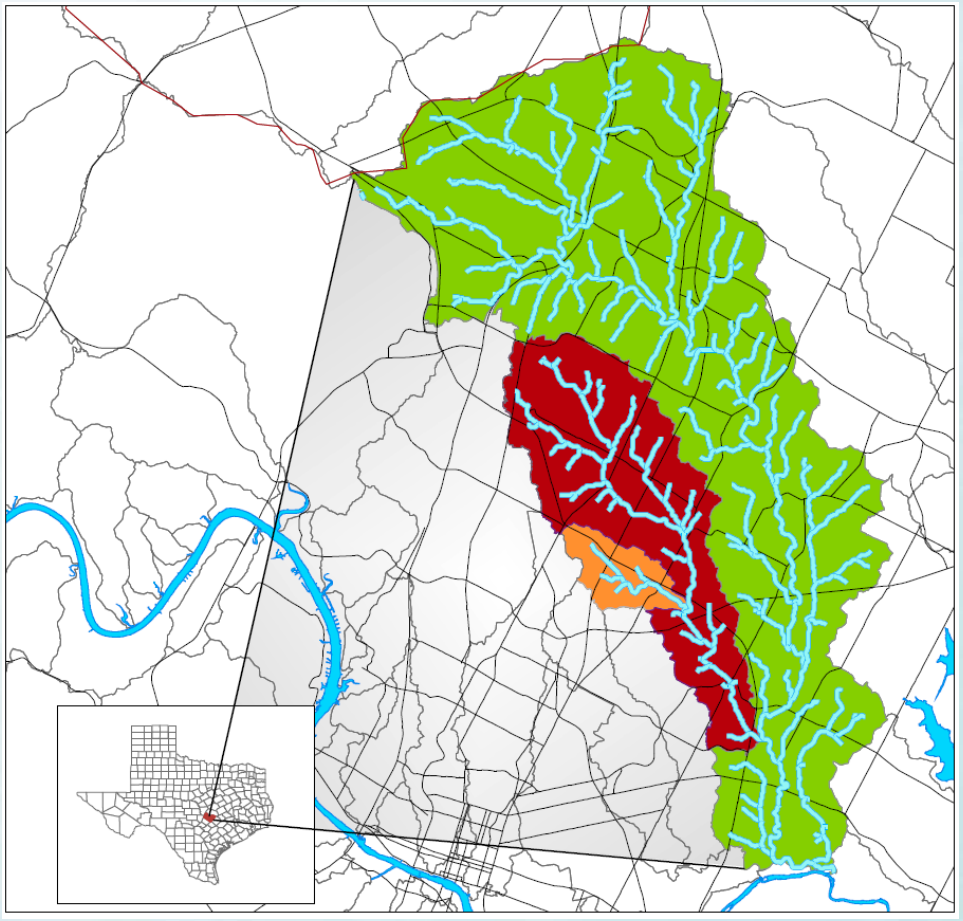
Metric	Definition
T_{dry}	fraction of time creek is dry (<0.003 cms)
BFR	baseflow to total flow ratio
F_{Ld} (days)	duration of low flow events
F_{Ln}	number of low flow events
Q_{mean} (cms)	mean flow rate
Q_{peak} (cms)	peak flow rate
Q_{90} (cms)	90th percentile flow rate
T_{3xQ50}	fraction of time $Q > 3xQ_{median}$
T_{Qmean}	fraction of time $Q > Q_{mean}$
$+_{mean}$ (cms)	average rate of rise
$-_{mean}$ (cms)	average rate of fall
F_{Hd} (days)	duration of high flow events
F_{Hn}	number of high flow events

Case Studies

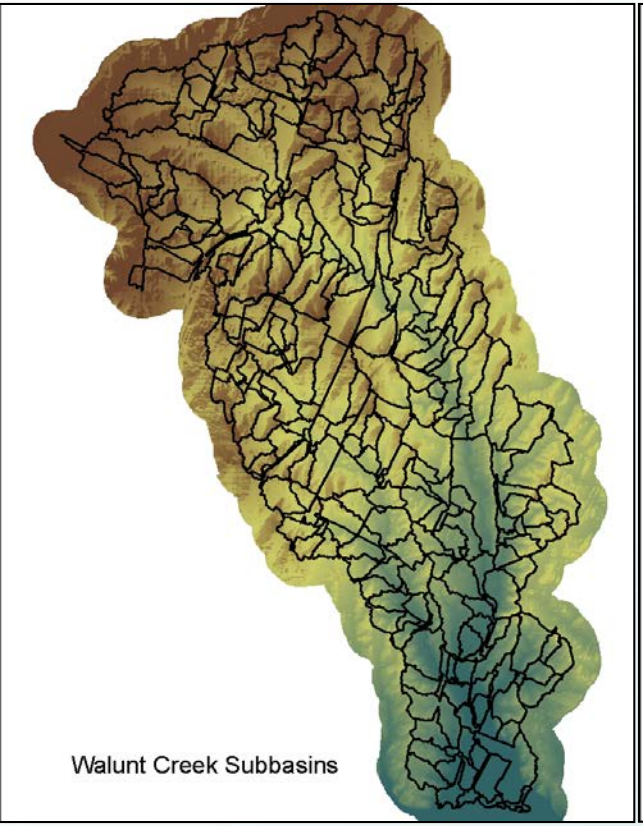
- Walnut Creek – Changes in Land Use
- Commons Ford Creek – Impacts of stormwater controls and size
- Gilliland tributary – Ordinance evaluation
- Brentwood tributary – LID controls
- Waller Creek – Centralized vs. distributed controls

Study Area - Walnut Creek

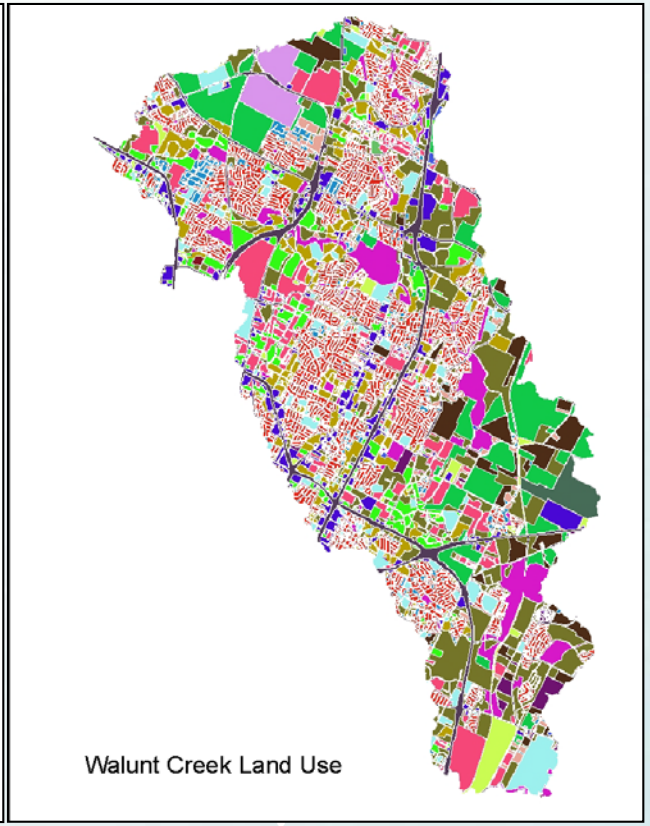
- 145.8 km^2 watershed
- USGS gage data 1967 to present
- 3-m DEMs
- SURRGO Soils
- 15-minute rainfall at 18 gauges
- Lot level land use
- 298 sub-basins
- ~4500 HRUs



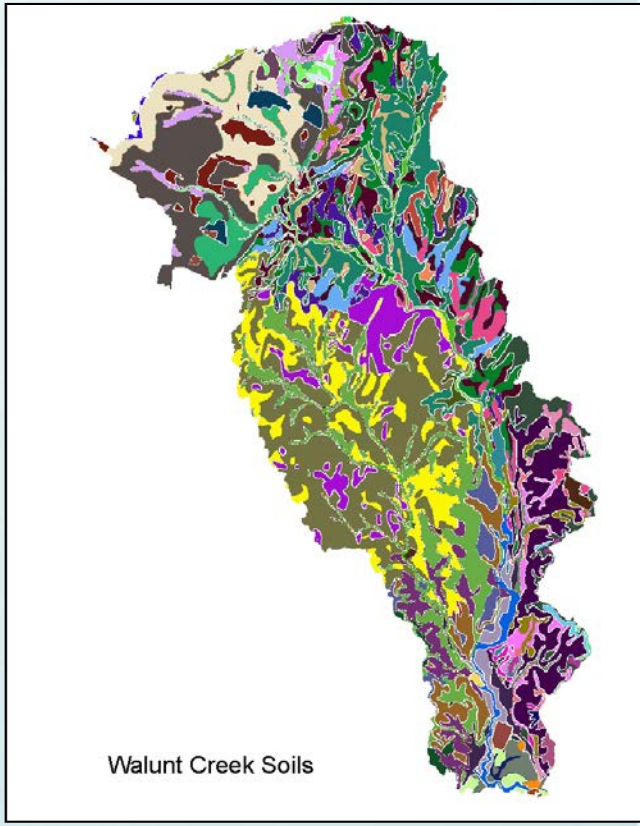
Study Area - Walnut Creek



Walunt Creek Subbasins



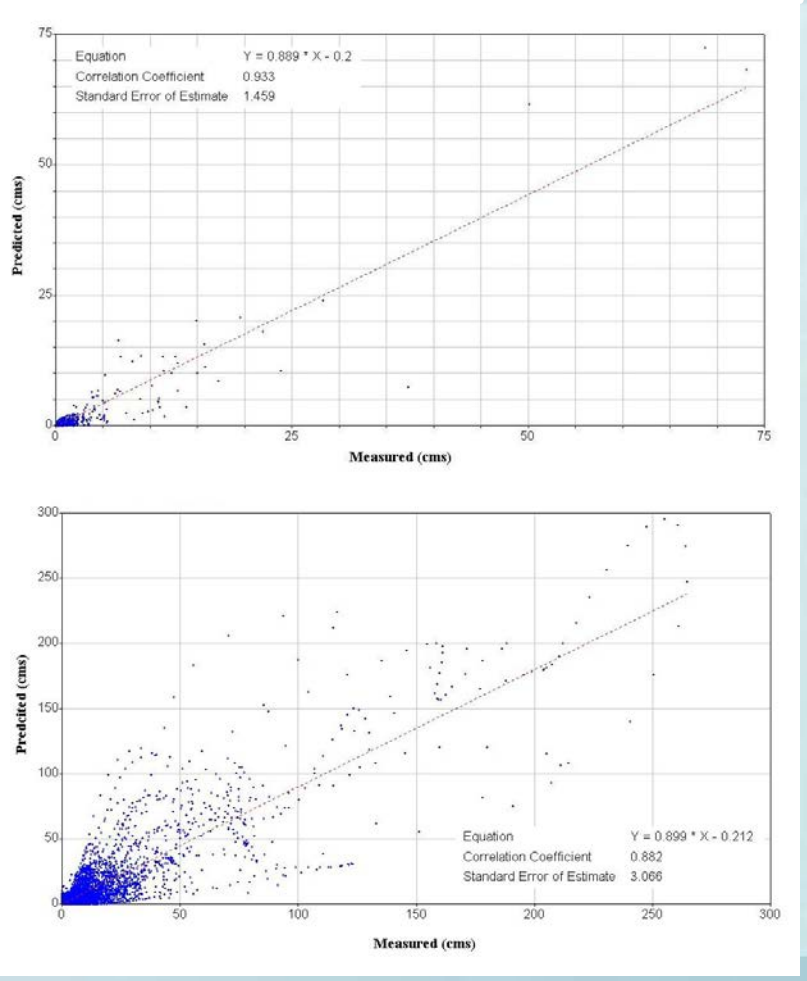
Walunt Creek Land Use



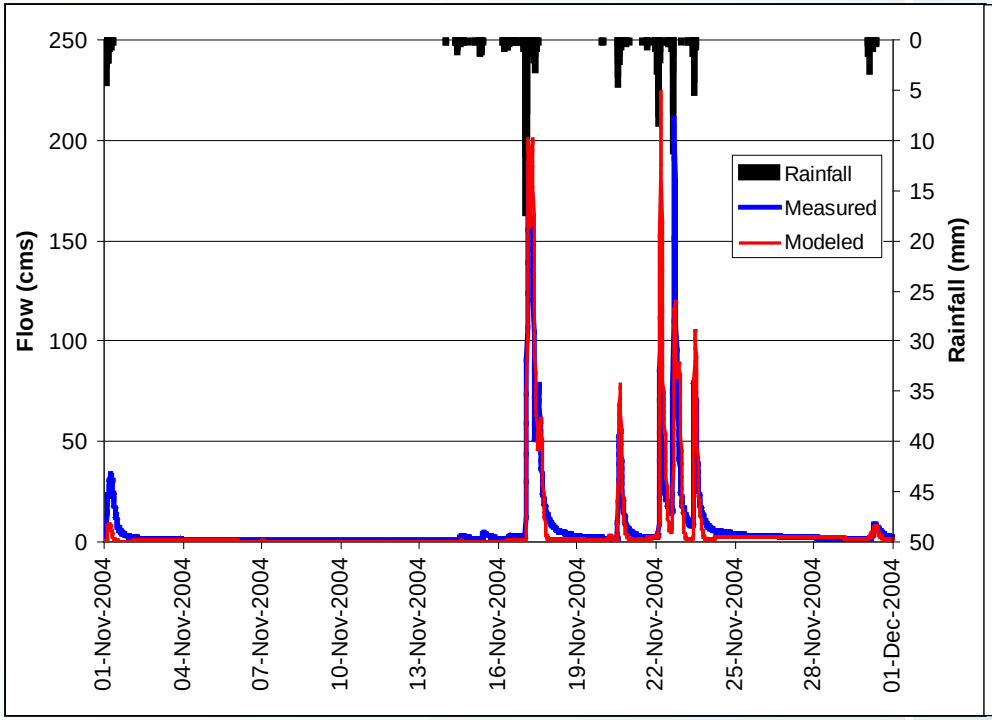
Walunt Creek Soils

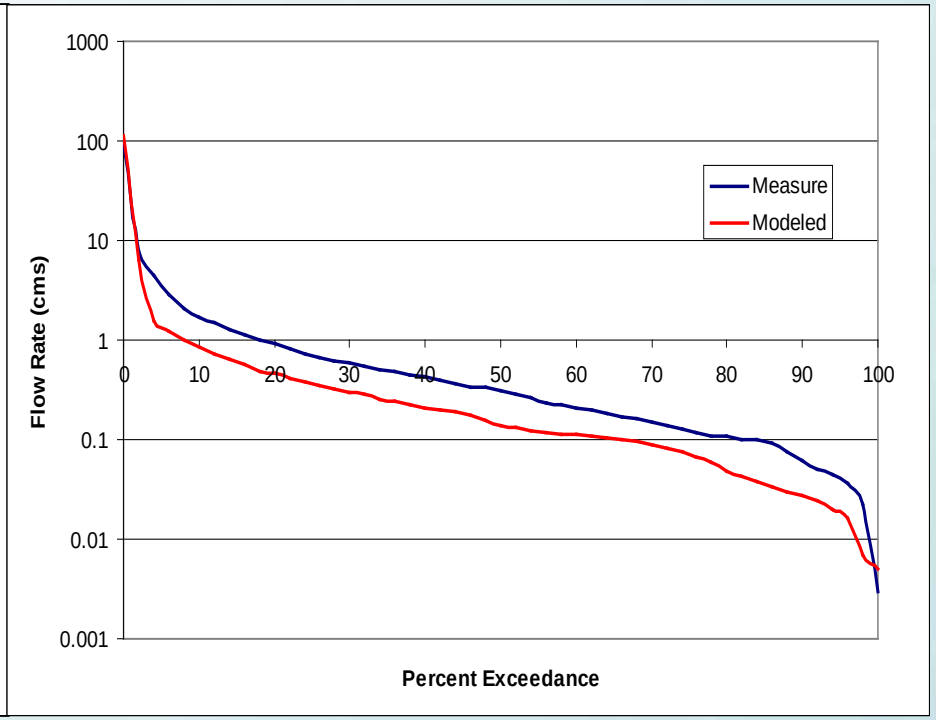
Calibration Results

- Daily – NSE = 0.86, $r^2 = 0.87$
- Sub-daily – NSE = 0.74, $r^2 = 0.78$
- Good storm flow baseflow ratio
- Under predicts total flow on most ranges
- Better predictions of hydrology than daily CN model.

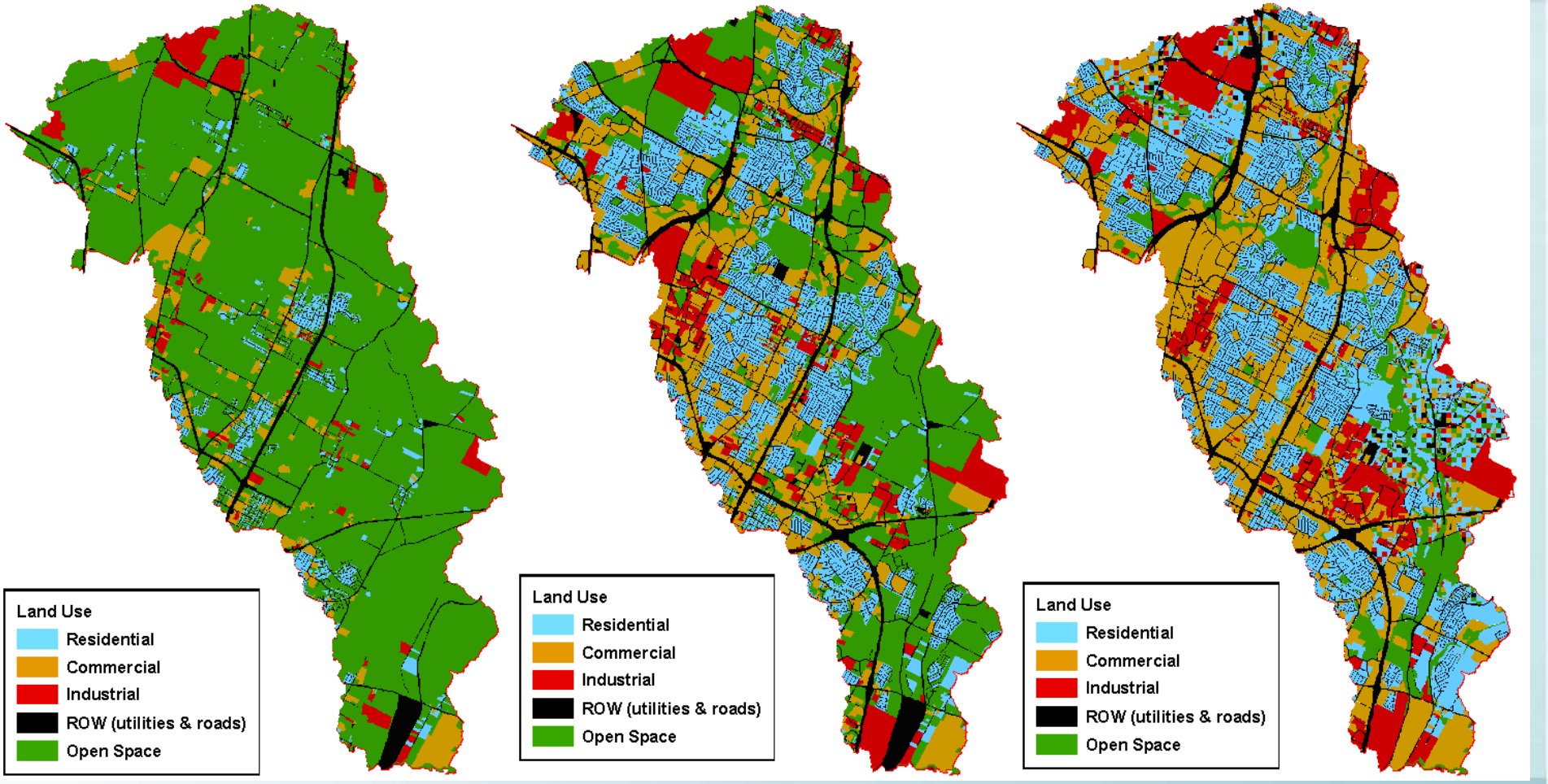


Calibration Results



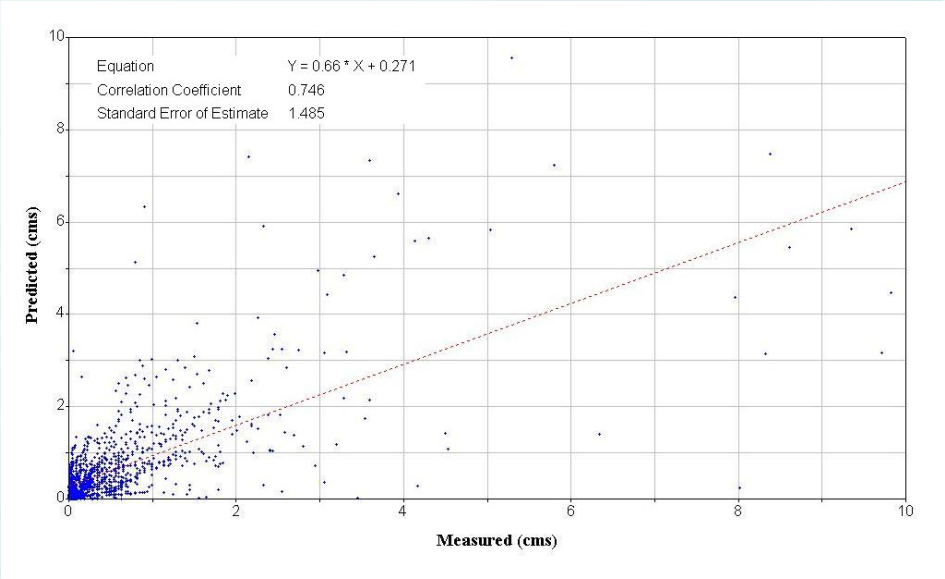


Walnut Land Use Scenarios

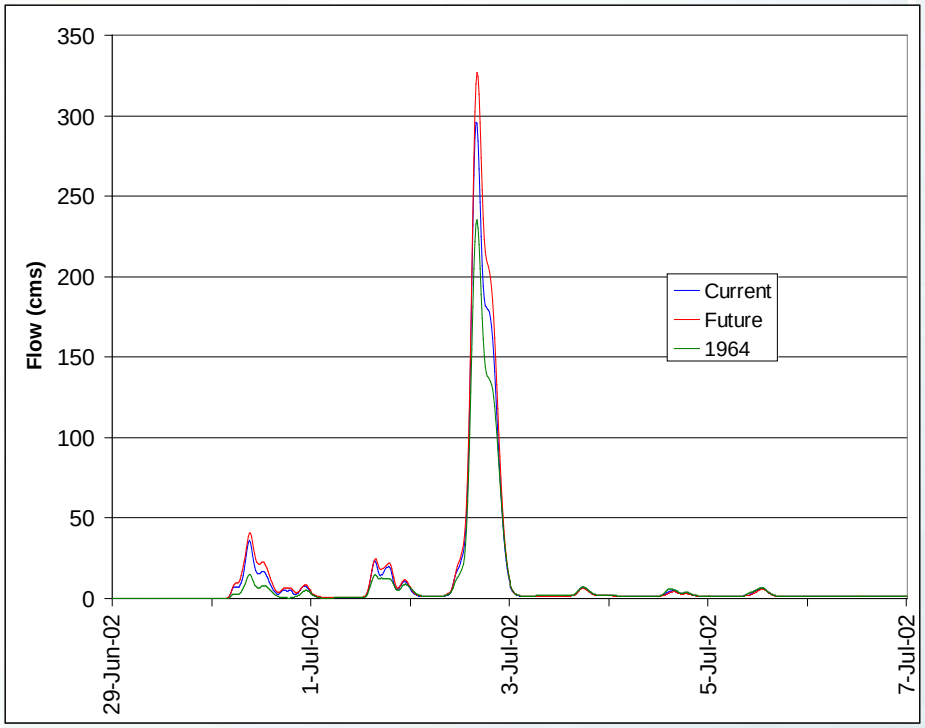


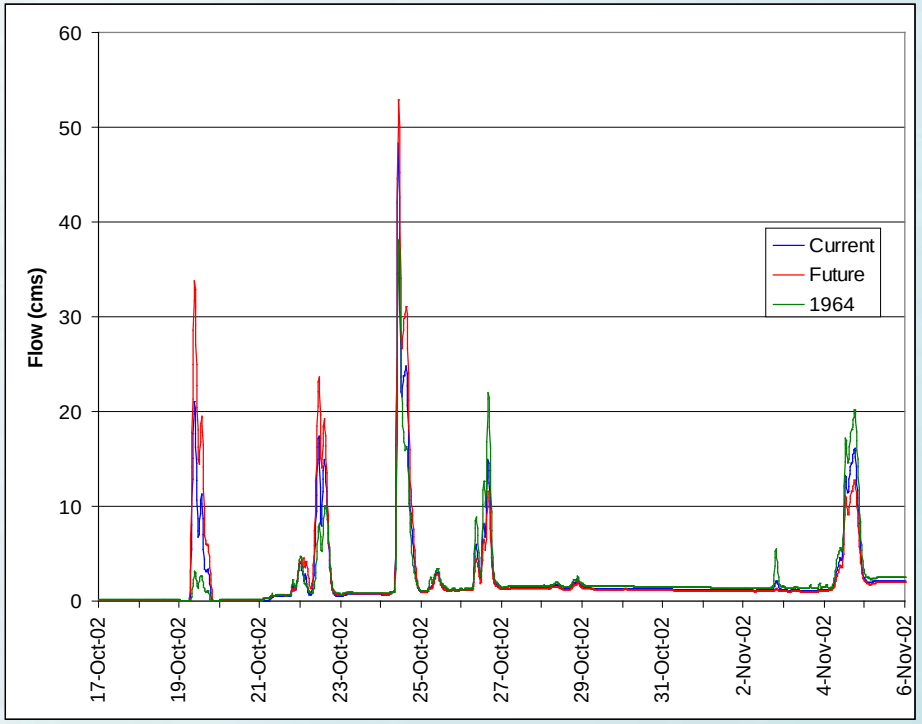
Model Validation

- Hourly rainfall
- Land use estimated from earlier period
- Daily only – NSE = 0.57, r2 = 0.56
- Baseflow ratio good
- Over predicted total flow

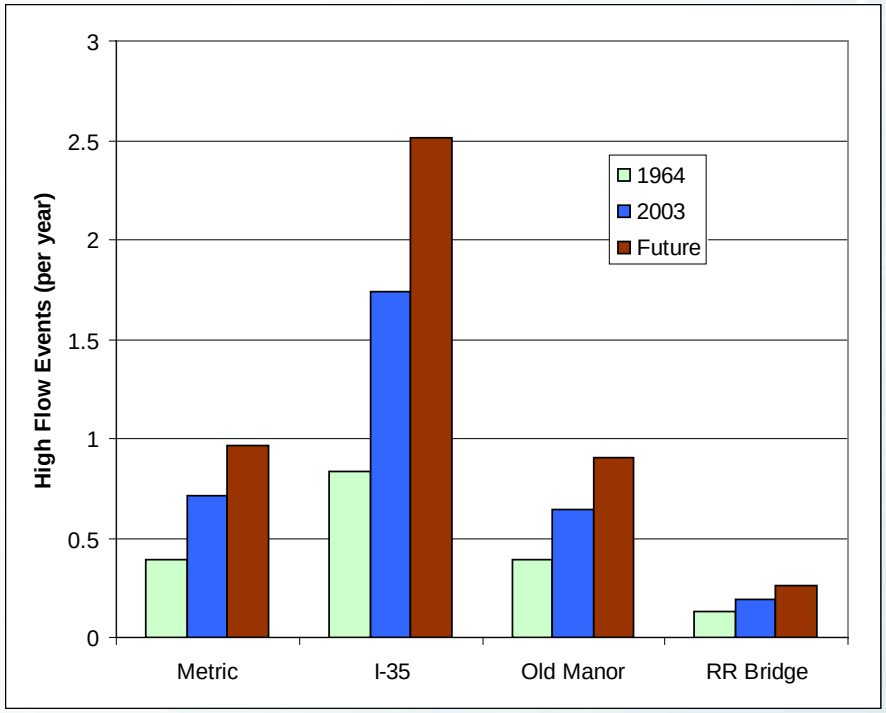


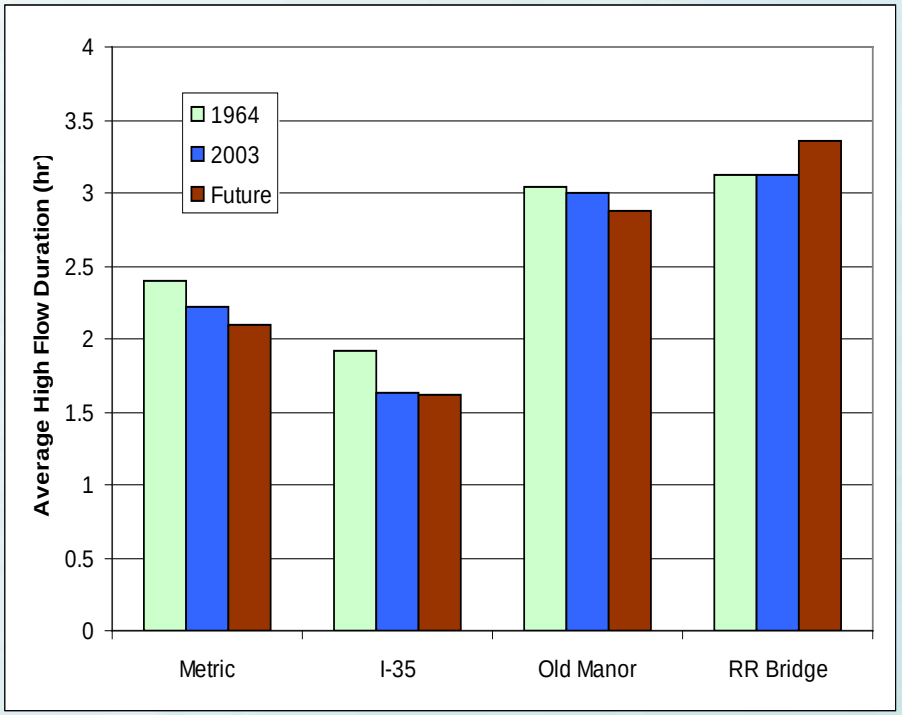
Model Results



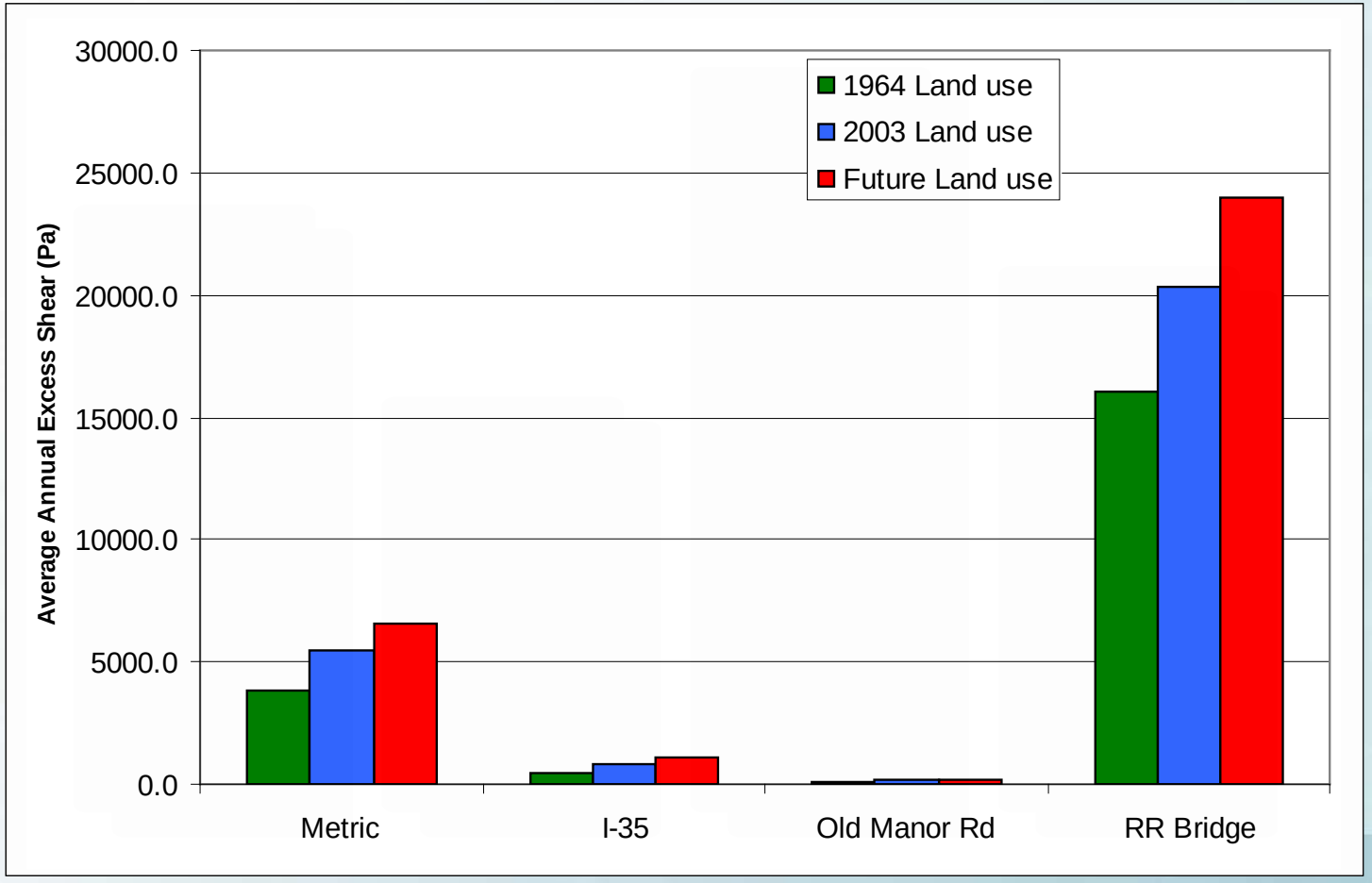


Flood Evaluation

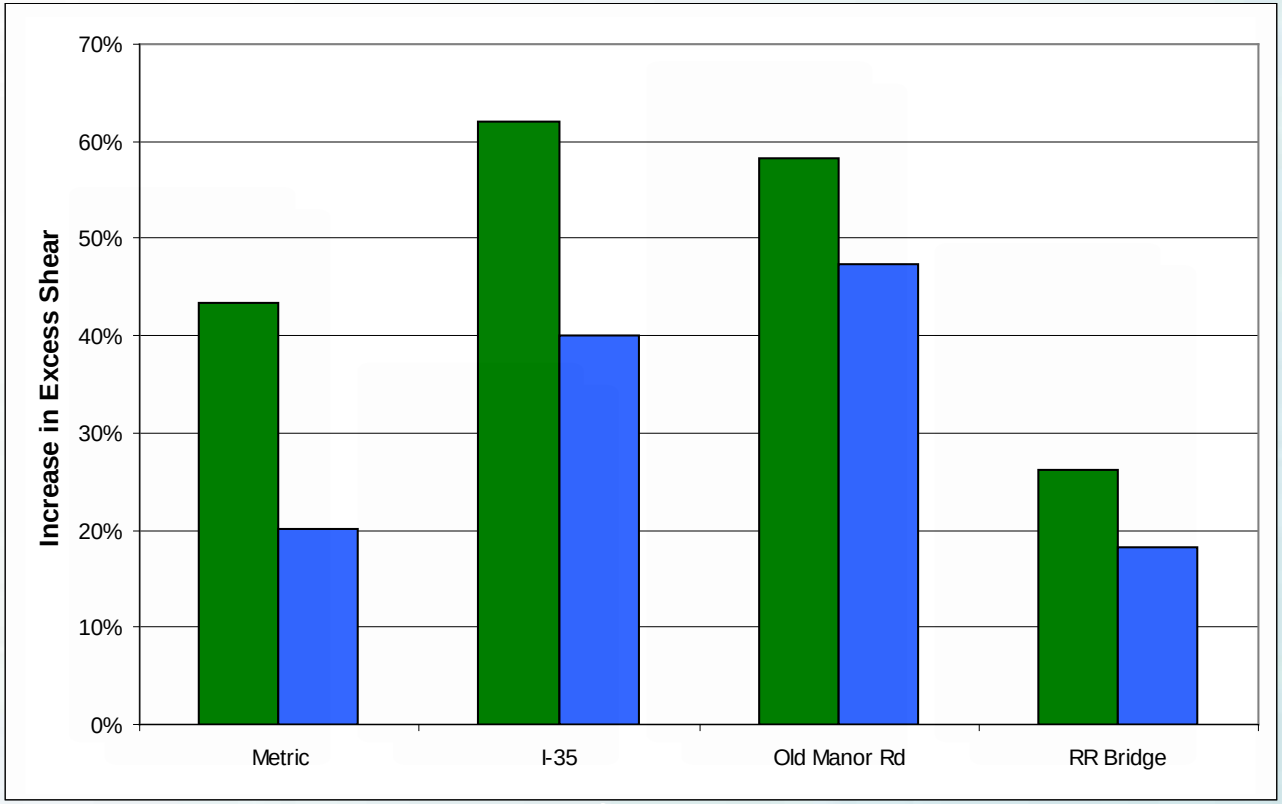




Erosion Evaluation



Erosion Evaluation

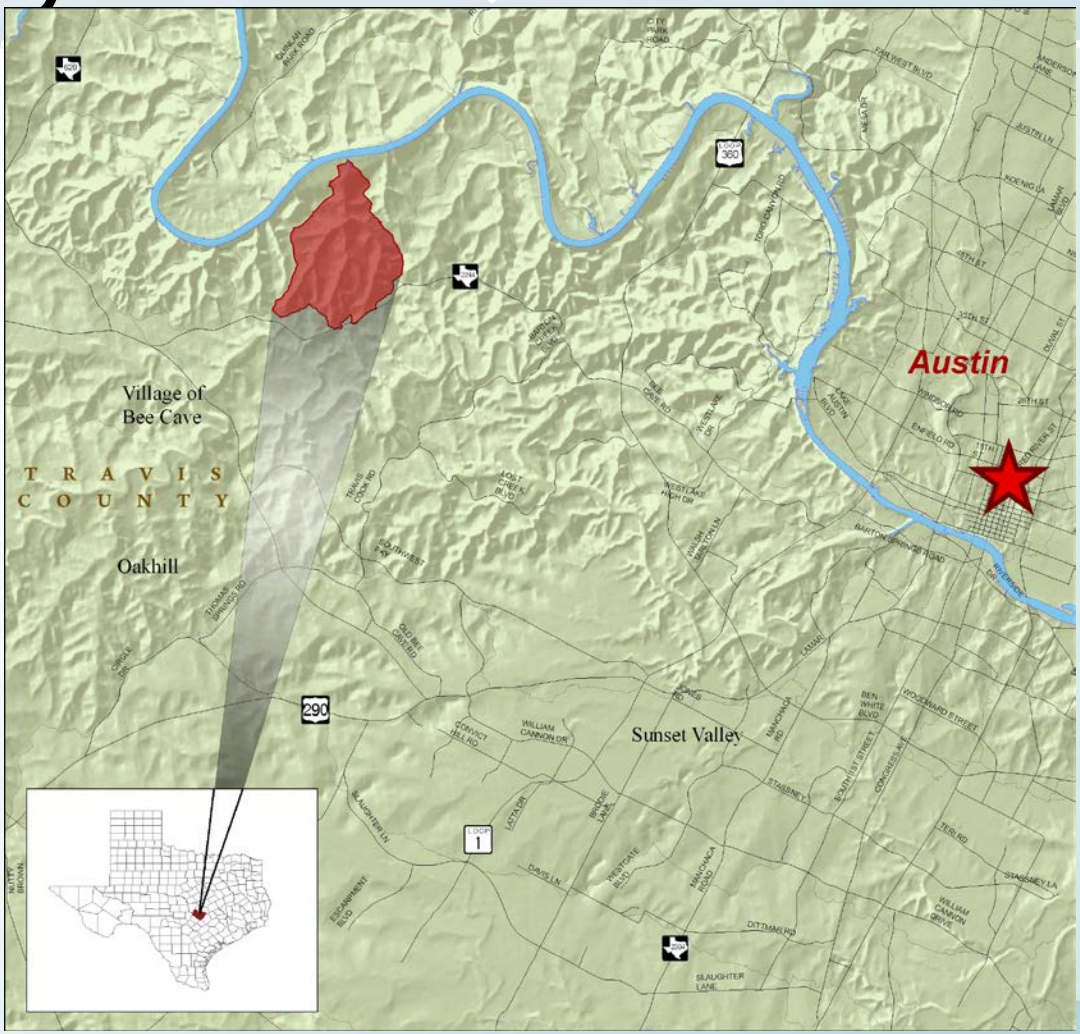


Predicted Response (AQP) of Aquatic Communities to Development

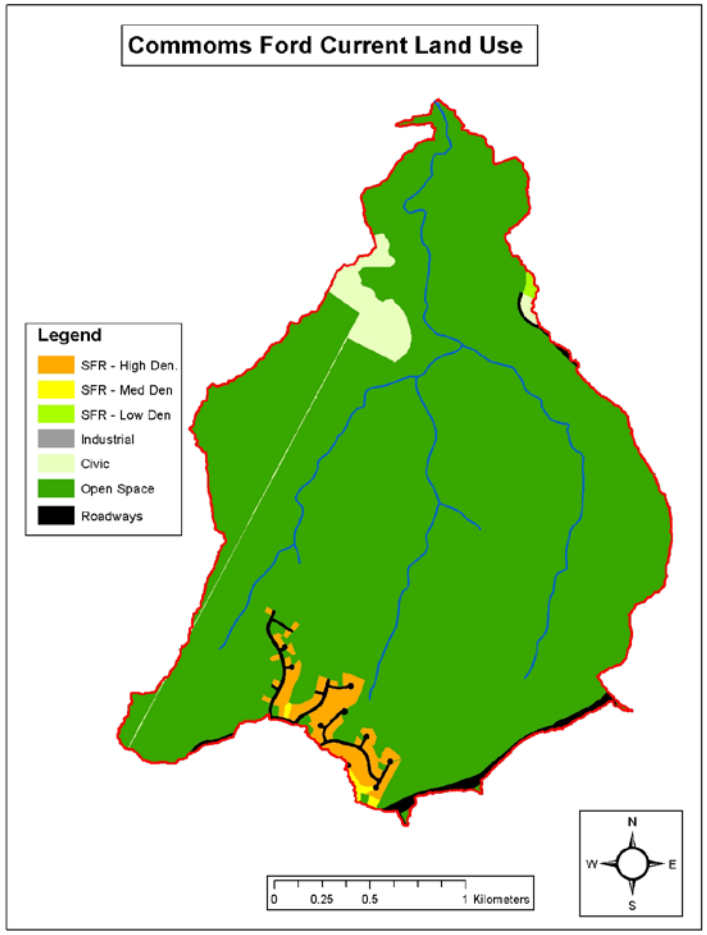
Conclusions

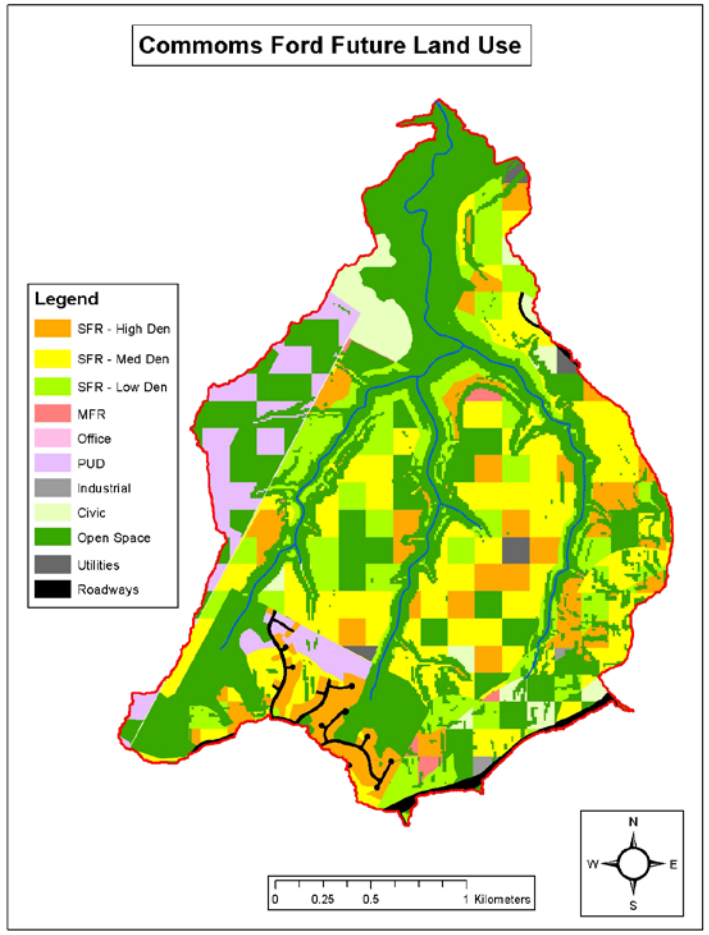
- In this case, only minor calibration adjustments in the sub-daily model were required.
- The sub-daily model results were better that the daily model results.
- Applying different land use scenarios to SWAT produces reasonable predictions of hydrology without further calibration.
- These results may be used to evaluate the impacts on flooding, erosion and water quality.

Study Area – Commons Ford

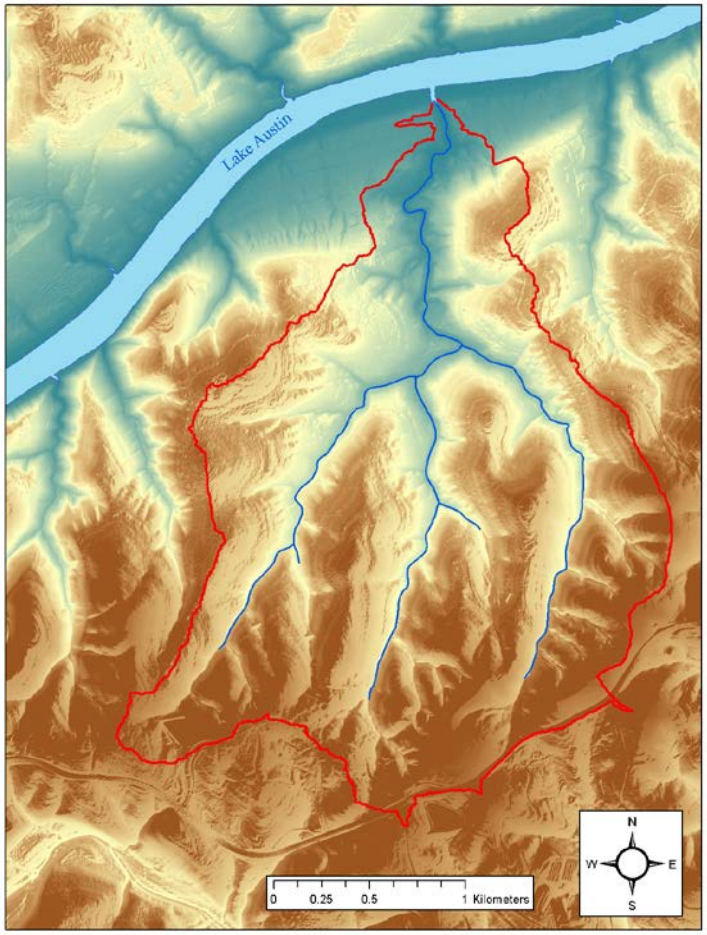


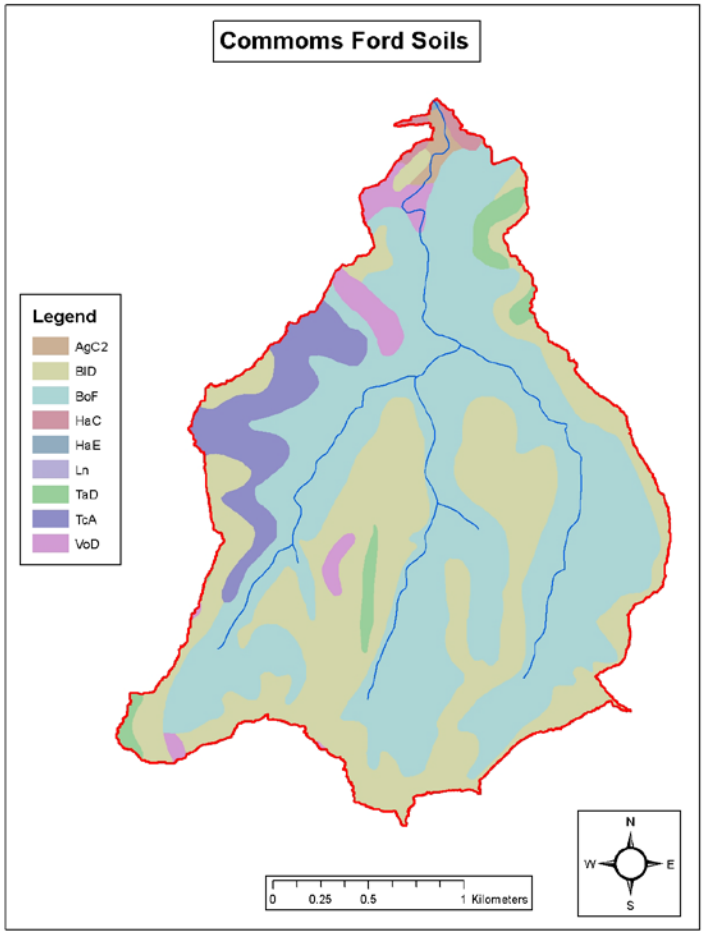
Study Area – Commons Ford



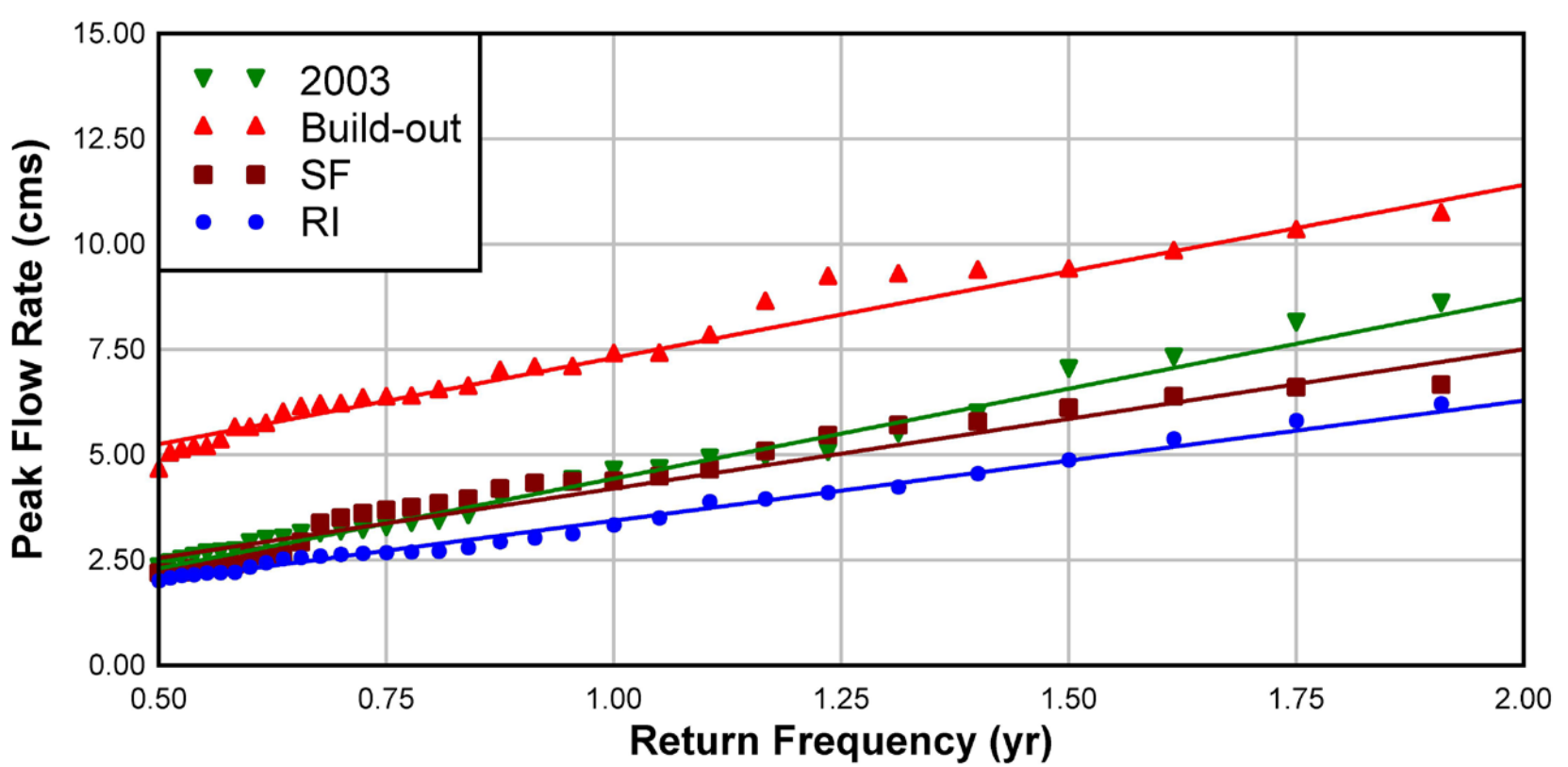


Study Area – Commons Ford Watershed

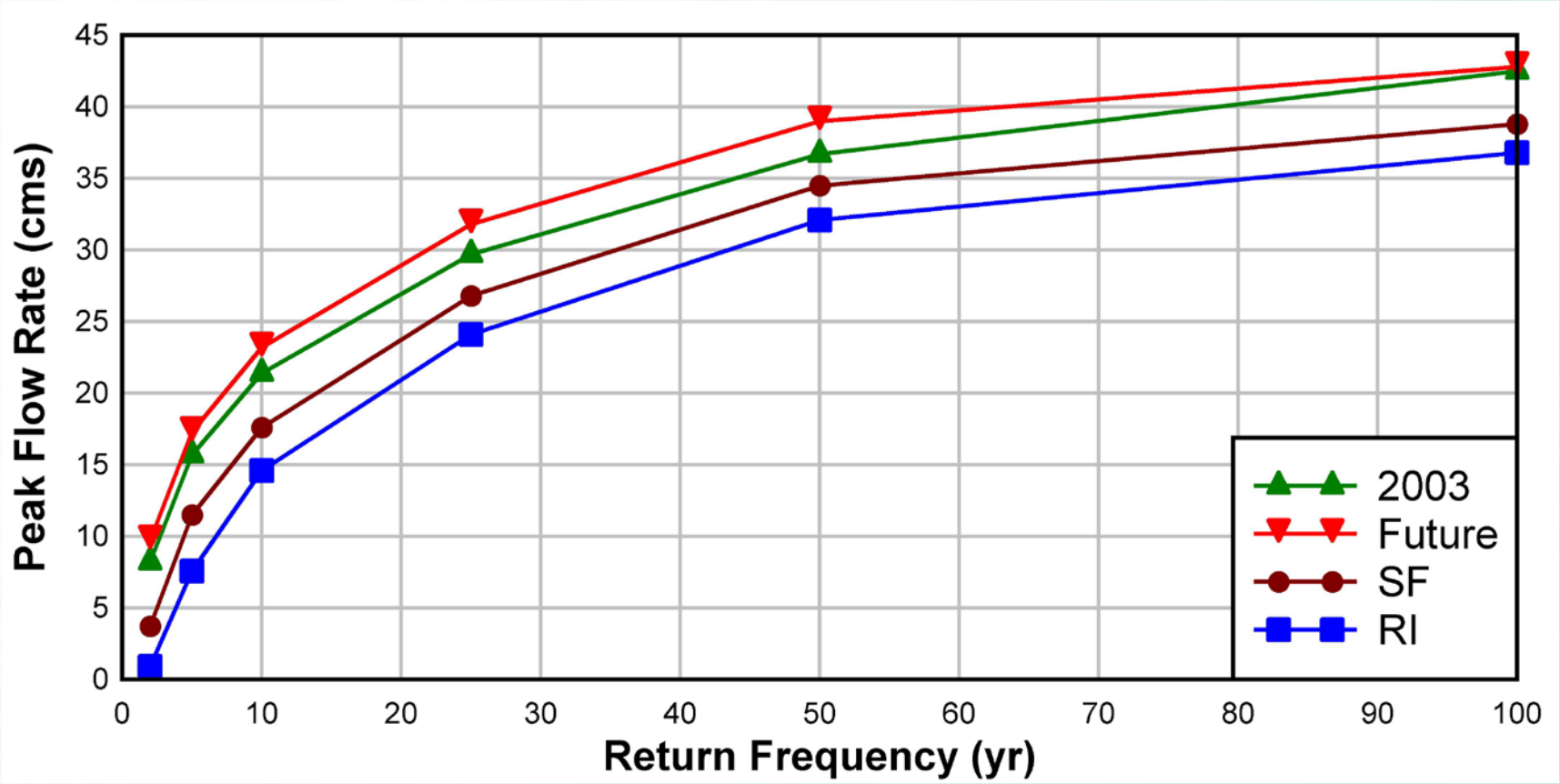




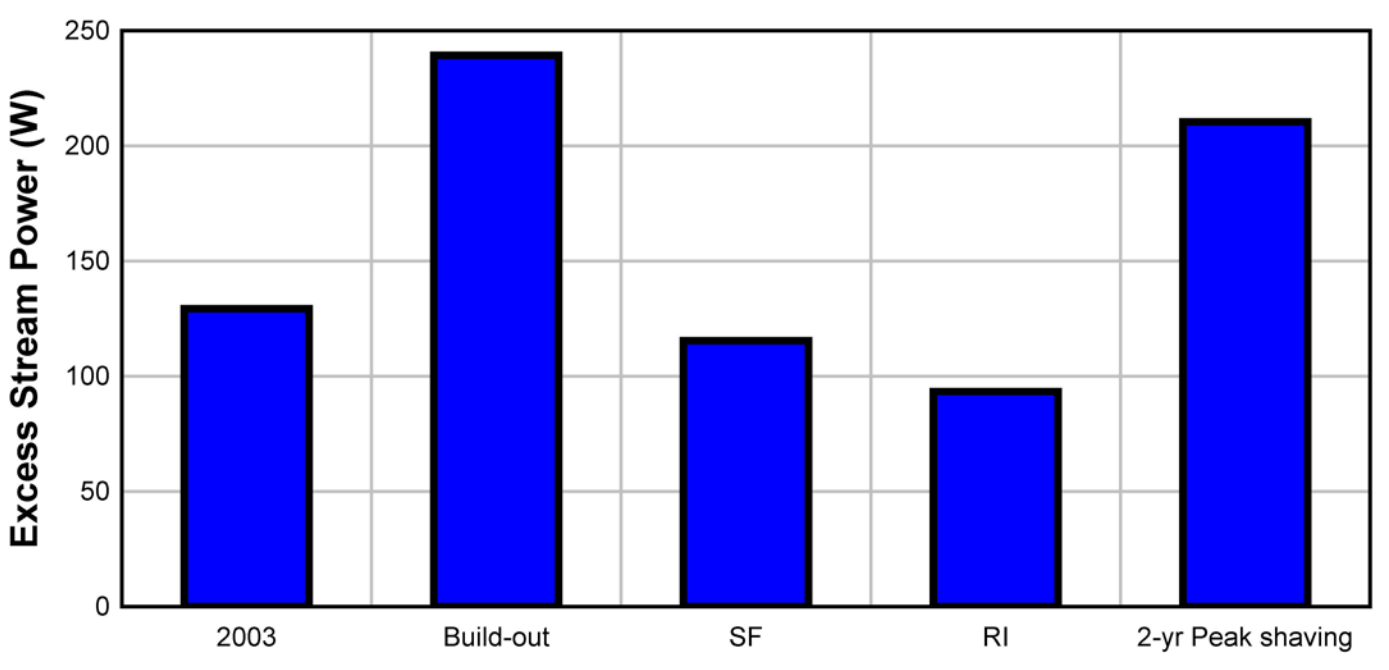
Flood Evaluation – Flow Analyses



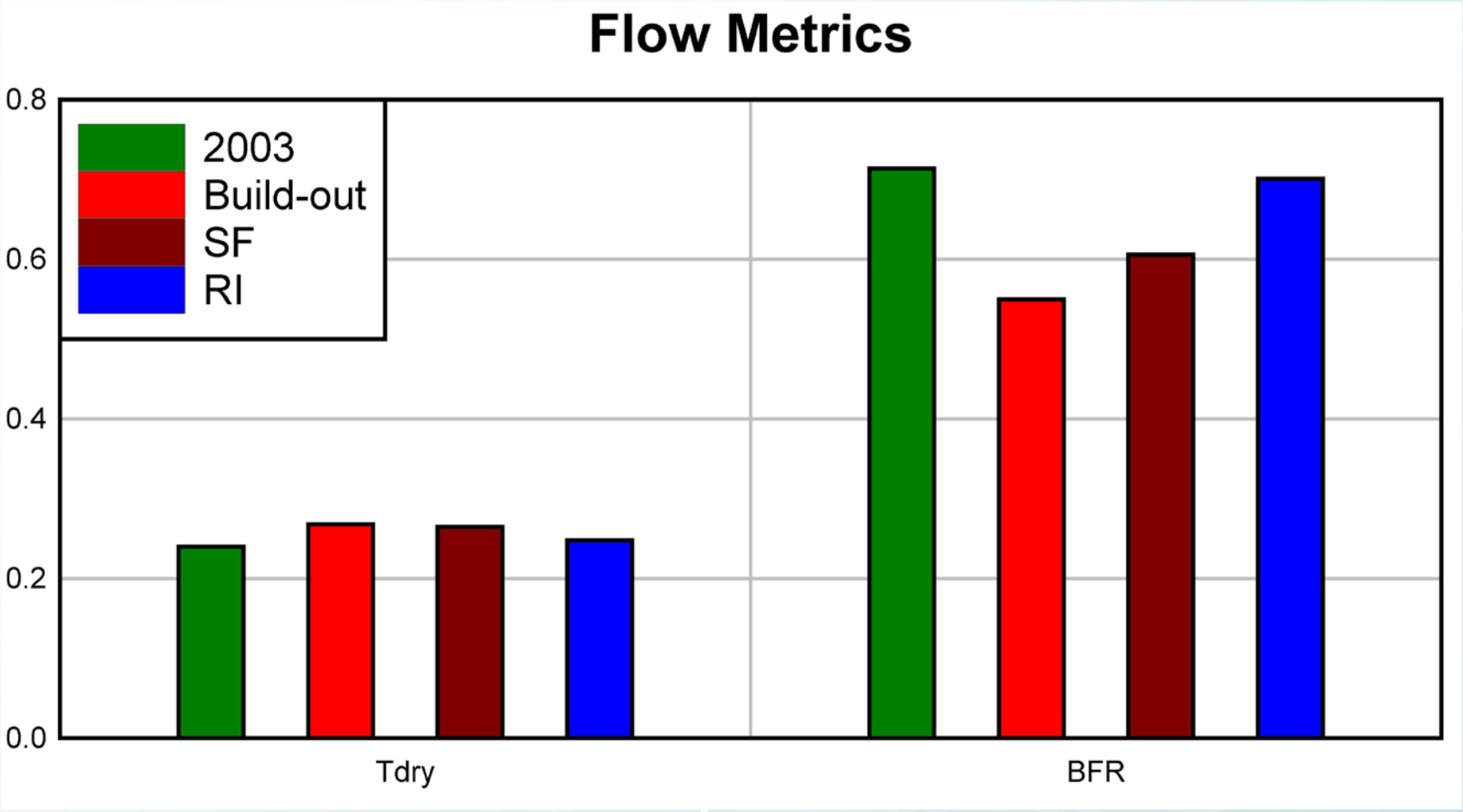
Flood Evaluation – Design Rainfall



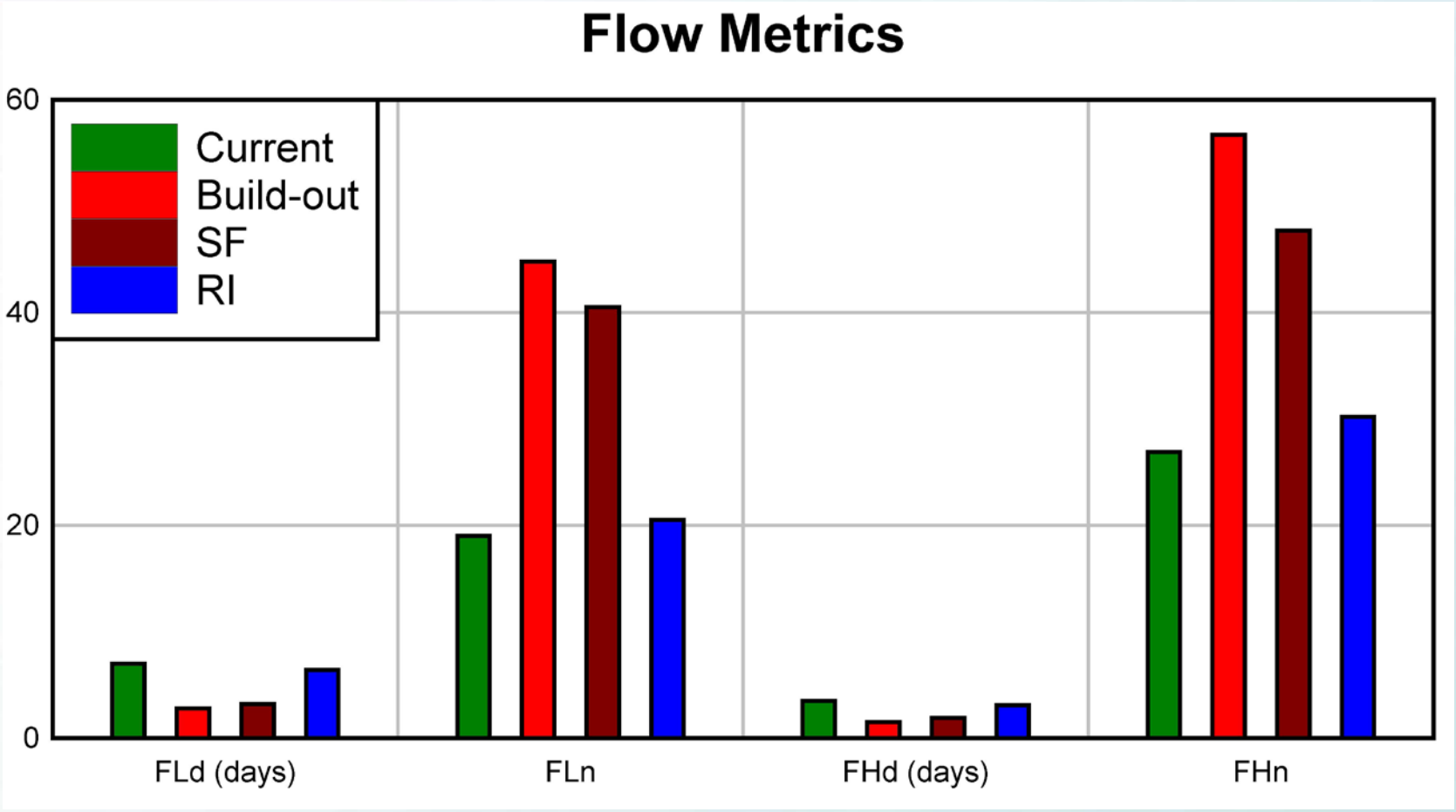
Erosion Change



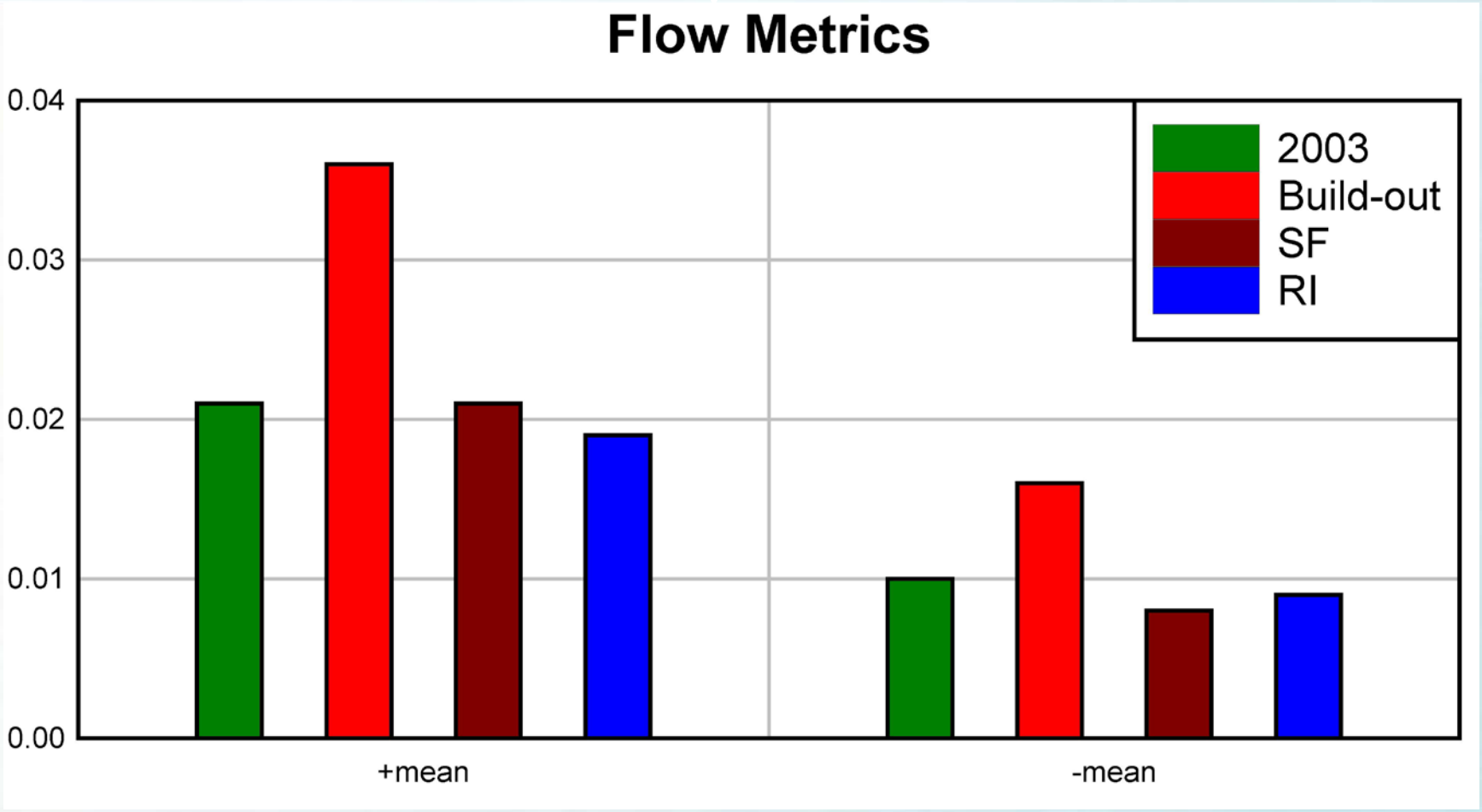
WQ Evaluation



WQ Evaluation



WQ Evaluation



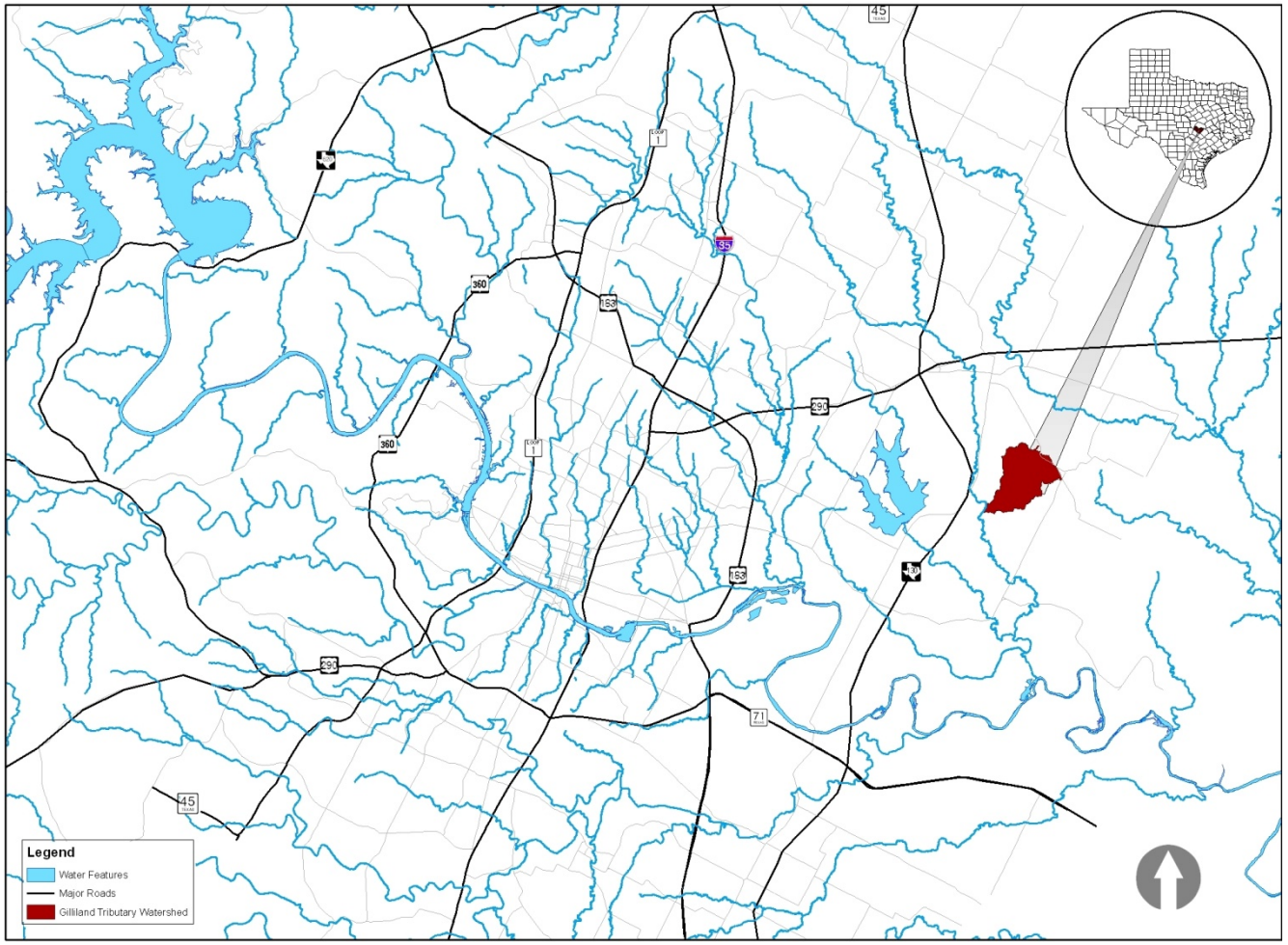
Conclusions

- Hydrology changes with increased development and SF and RI controls may mitigate some of those changes.
- SF and RI controls may reduce ESP to near undeveloped levels, traditional detention controls have little impact

Conclusions (cont.)

- SF and RI controls may reduce the increased flood potential for both frequent and rare events
- RI controls more closely mimic background conditions with respect to ALP hydrologic metrics.
- SF controls have beneficial impacts on some ALP metrics but lower impacts on others.

Gilliland Study Area



City of Austin Ordinances: Land Use & Controls

Undeveloped [UND]

Pre-Waterways Ordinances [Pre-ORD], <1974

- No controls
- Limited creek easements, >320 ac.

Waterway Ordinance [WO], 1974-1986

- Detention only
- Wider easements, >320 ac

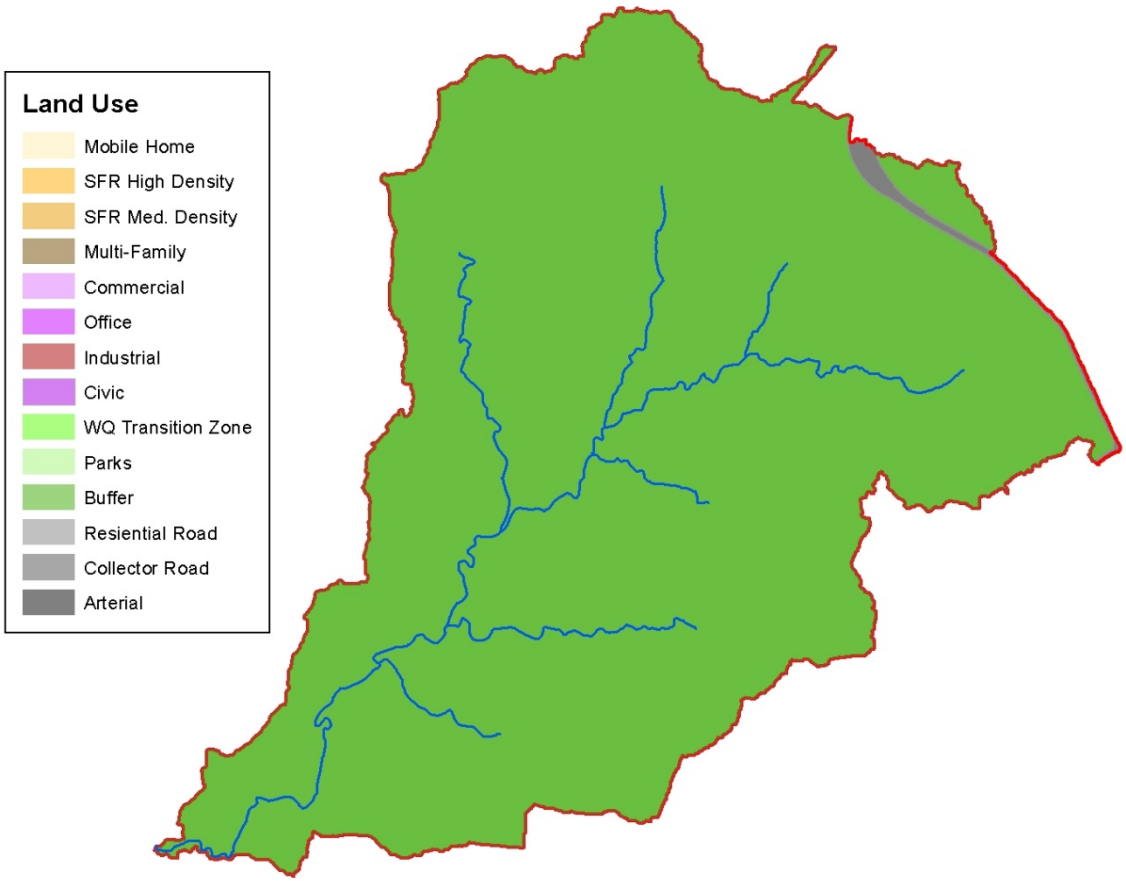
Comprehensive Watershed Ordinance [CWO], 1986-present*

- Detention and ½”+ sed-fil
- Creek buffer and water quality transition zone, >320 ac

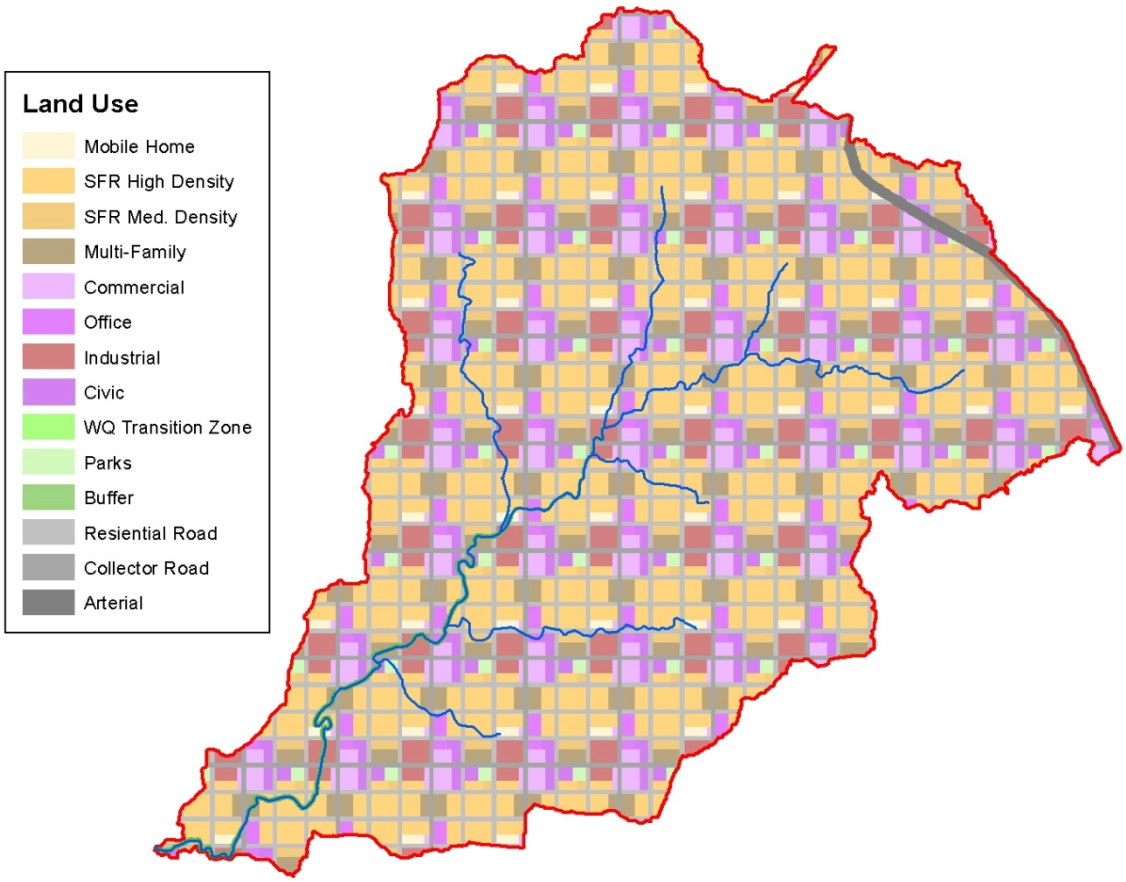
Watershed Protection Ordinance [WPO], proposed

- Detention and ½”+ sed-fil
- Creek buffer, >64 ac (no WQTZ)

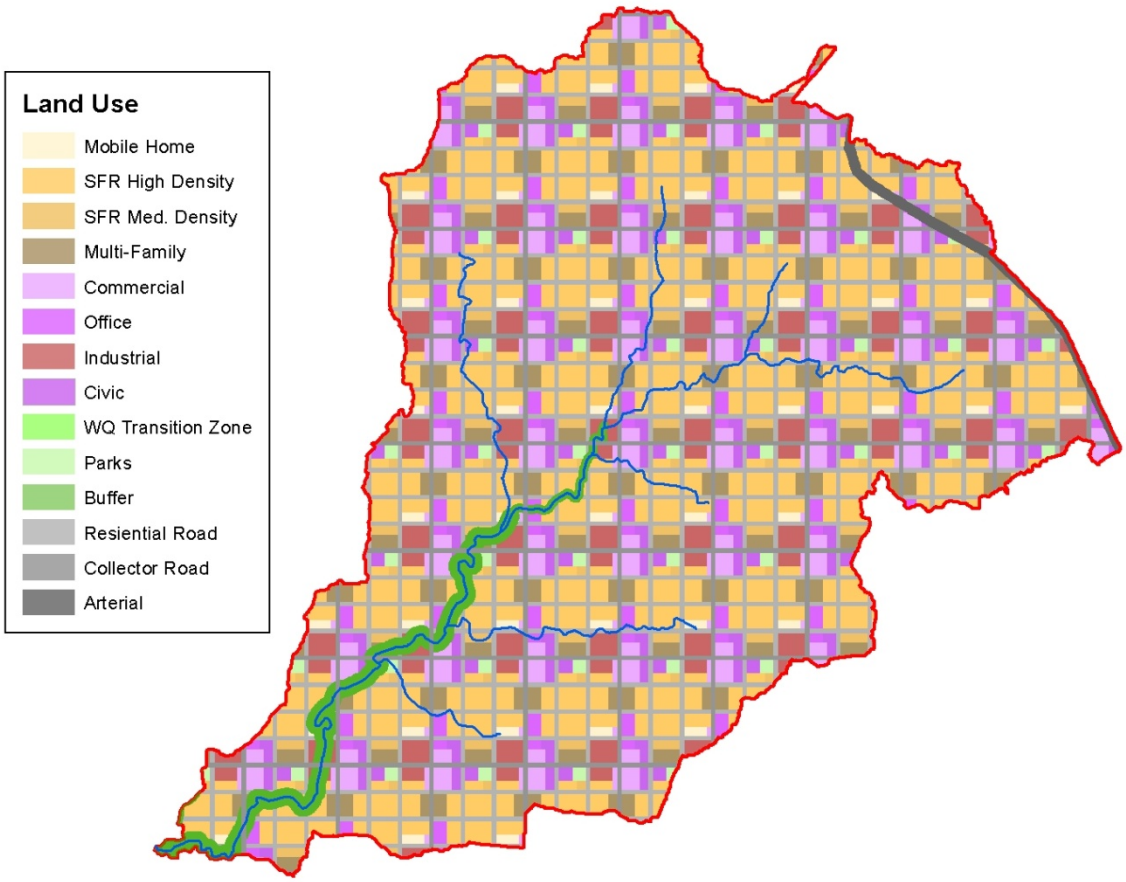
Undeveloped Land Use



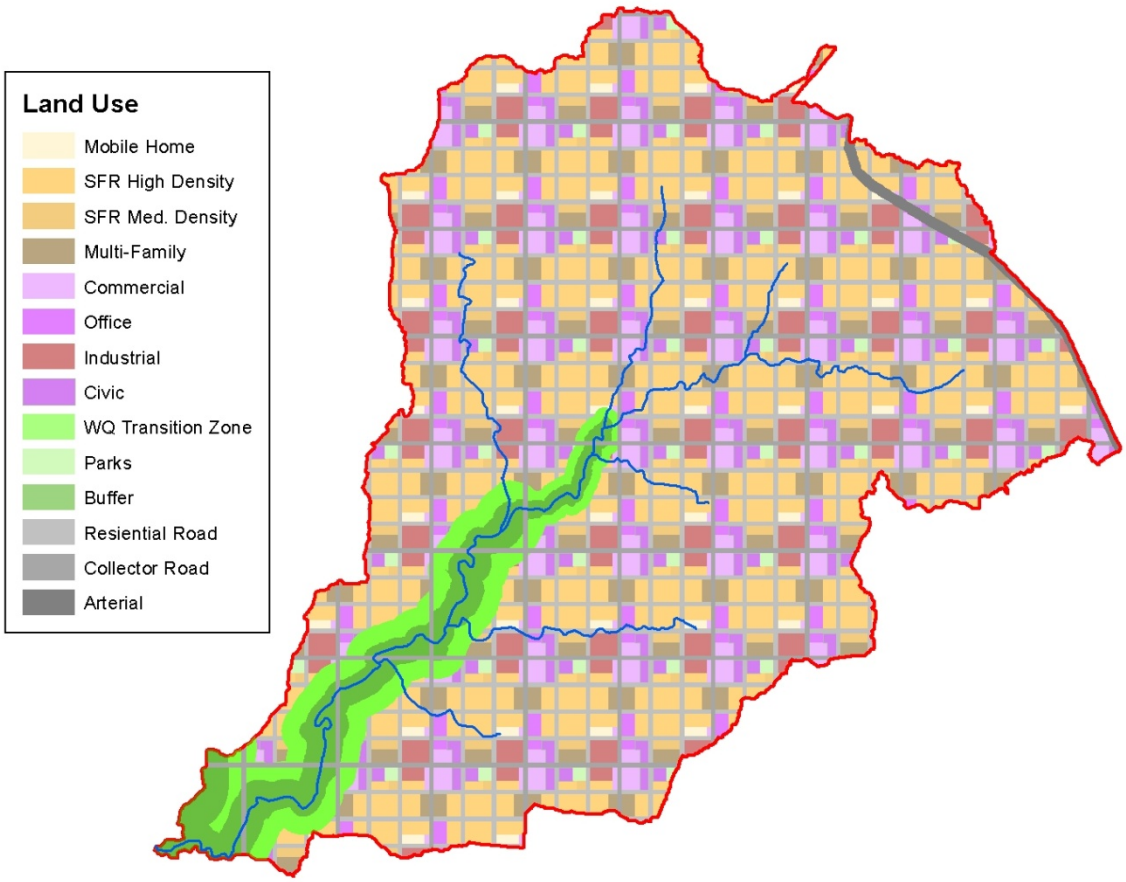
Pre-Ord Land Use (<1974)



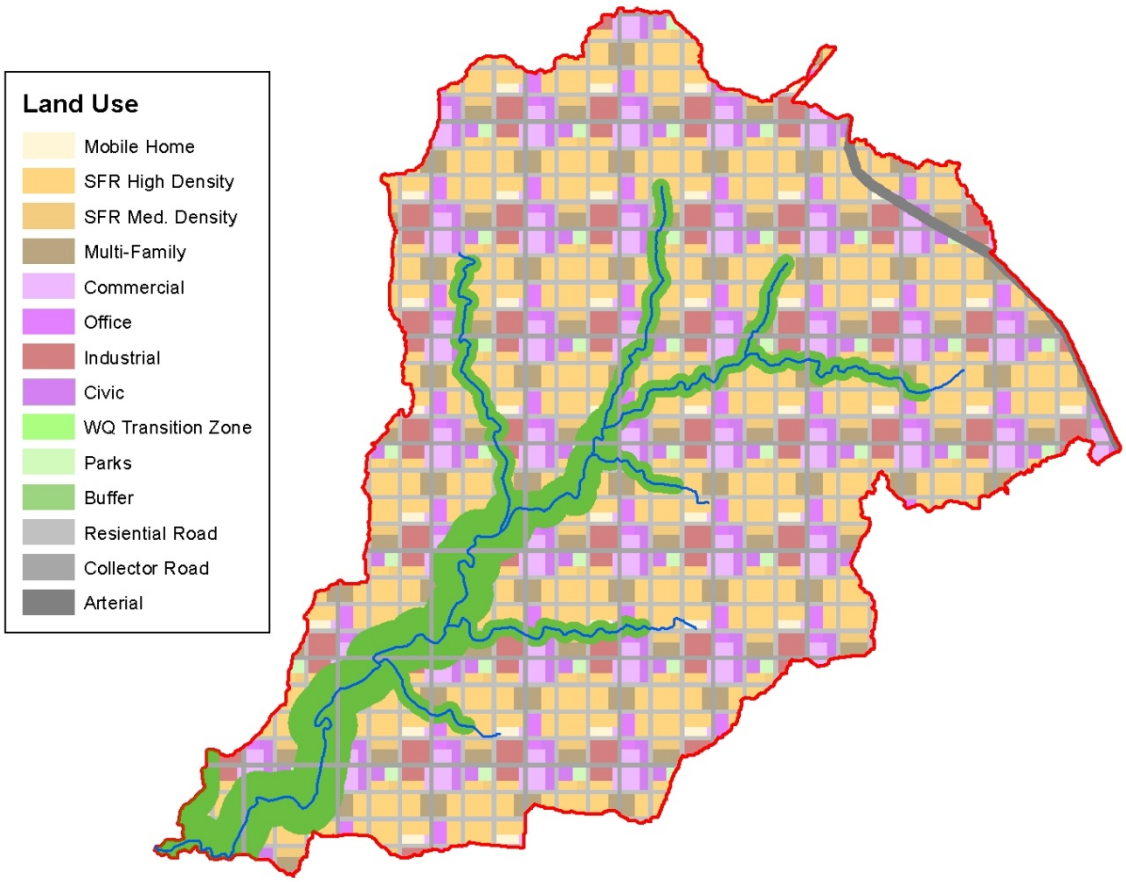
WO Land Use (~1974-86)



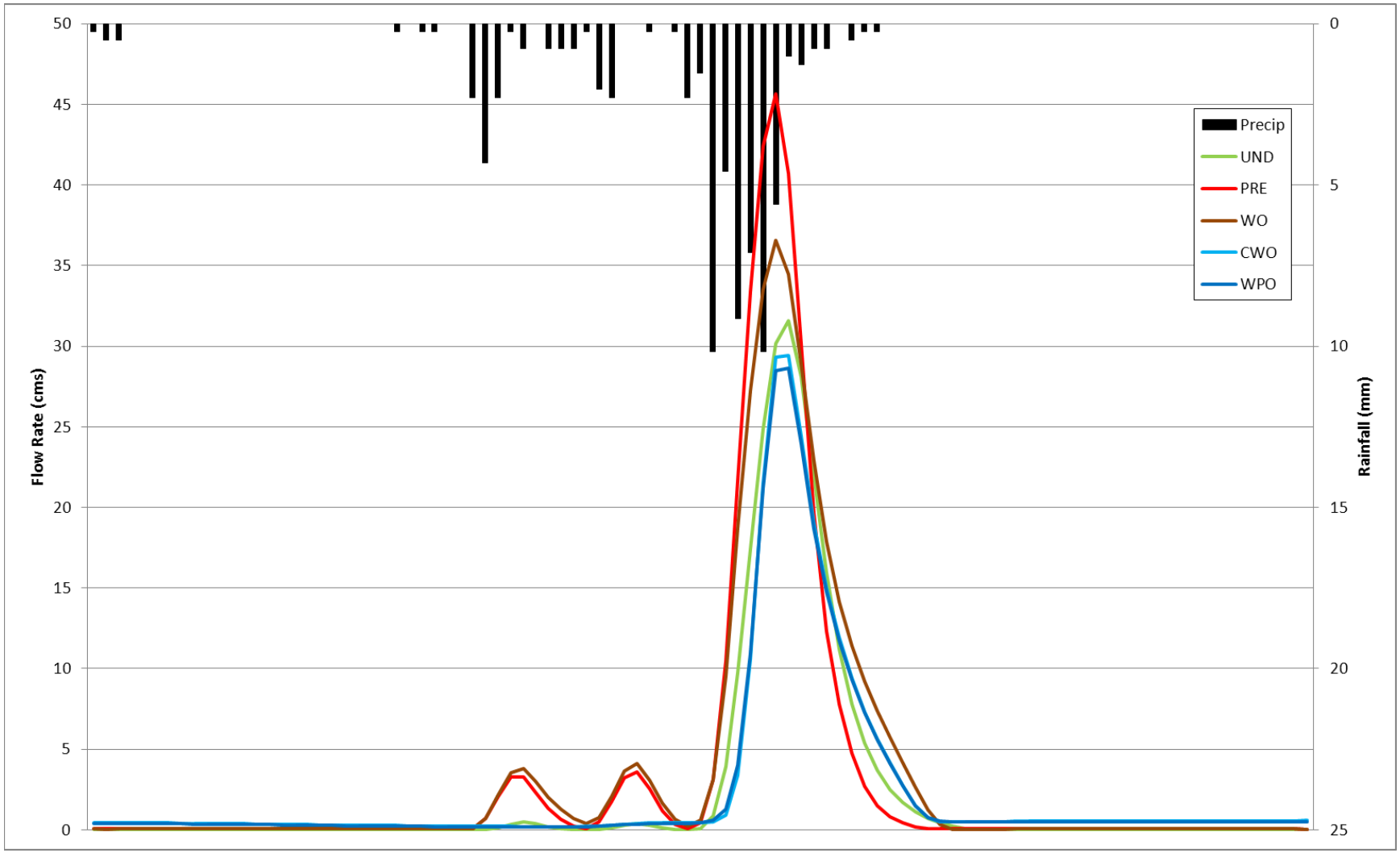
CWO Land Use (1986-present)



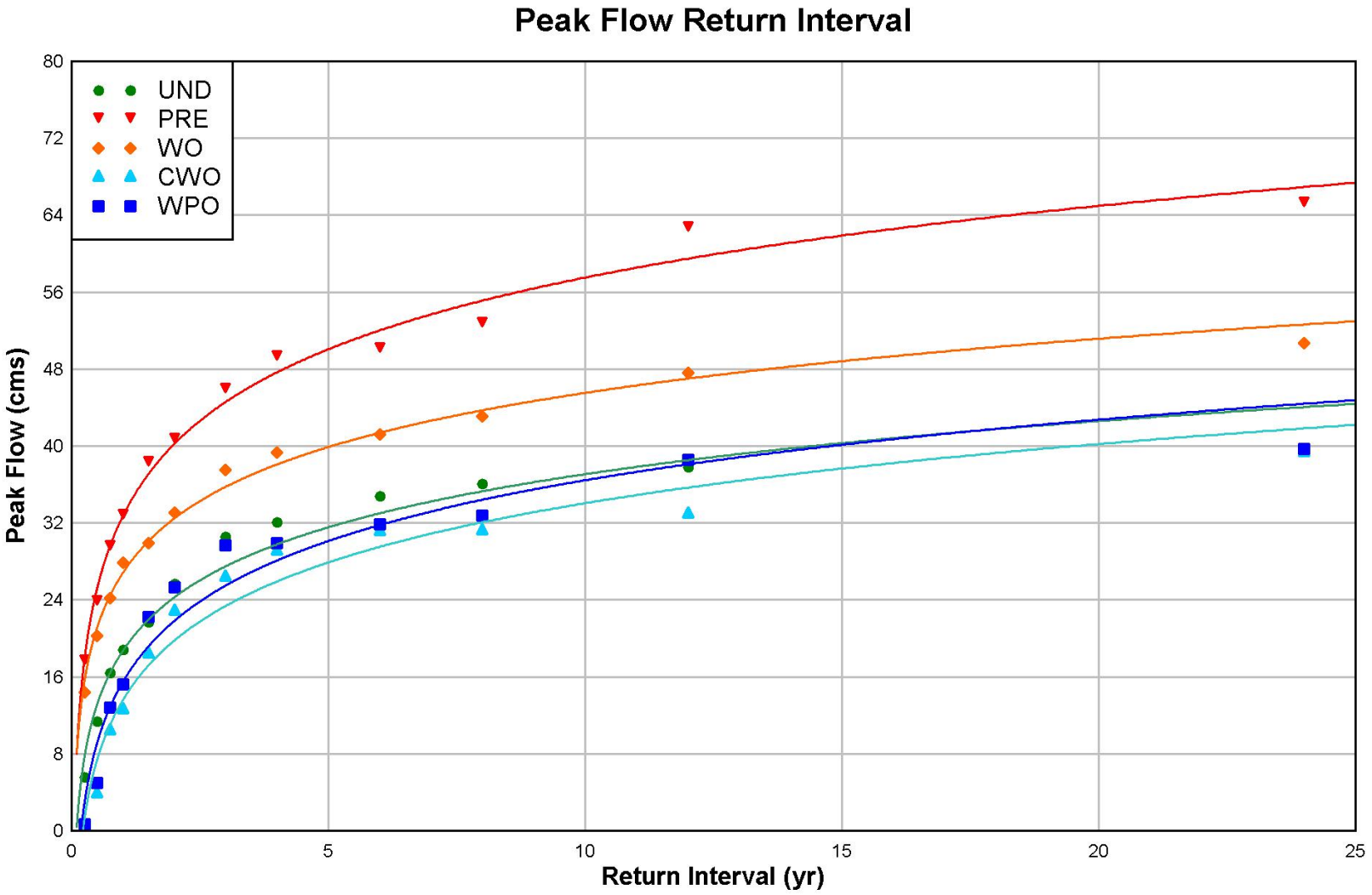
WPO Land Use (proposed)



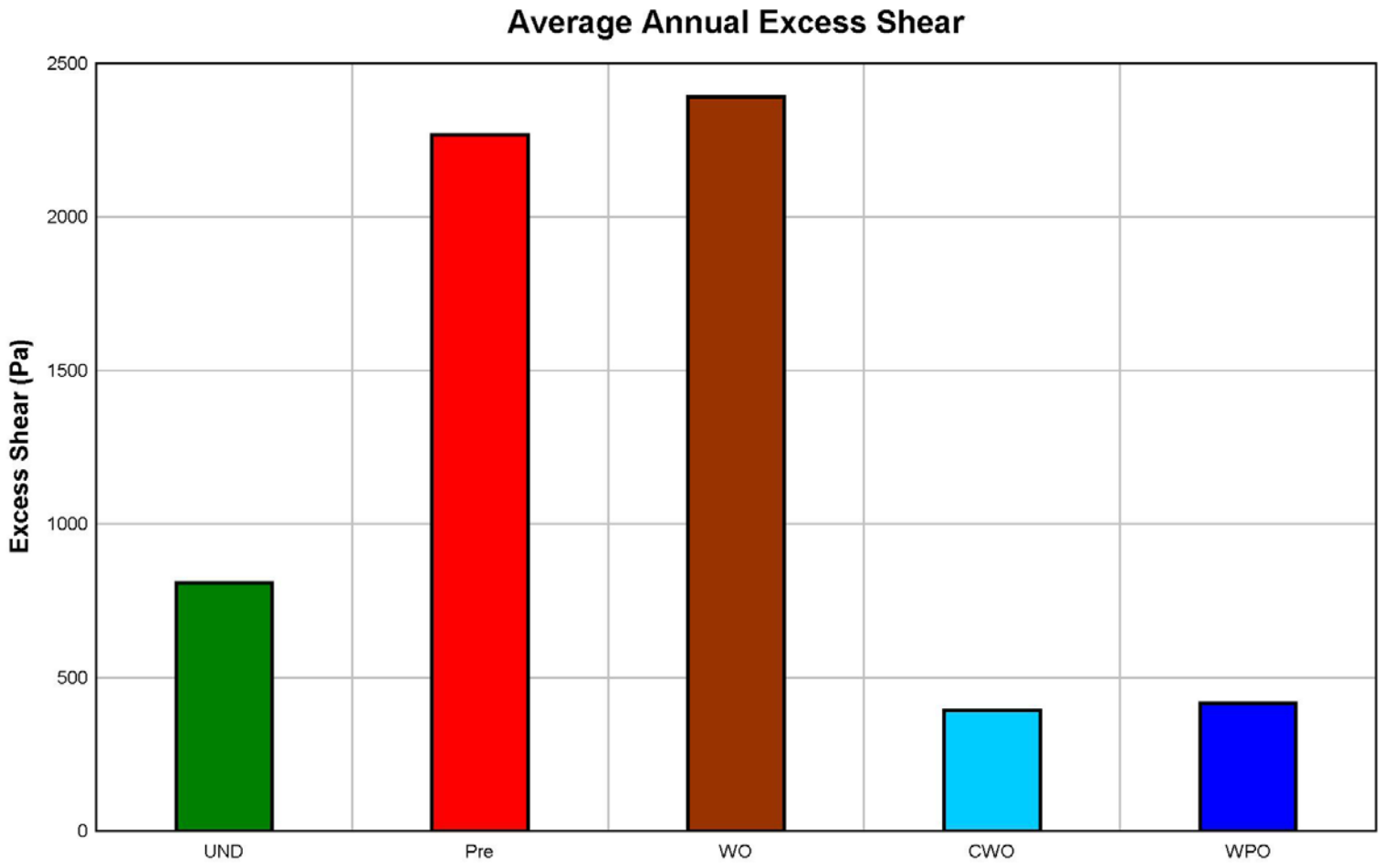
Effects of Ordinances



Impacts on Flooding



Impacts on Erosion Potential

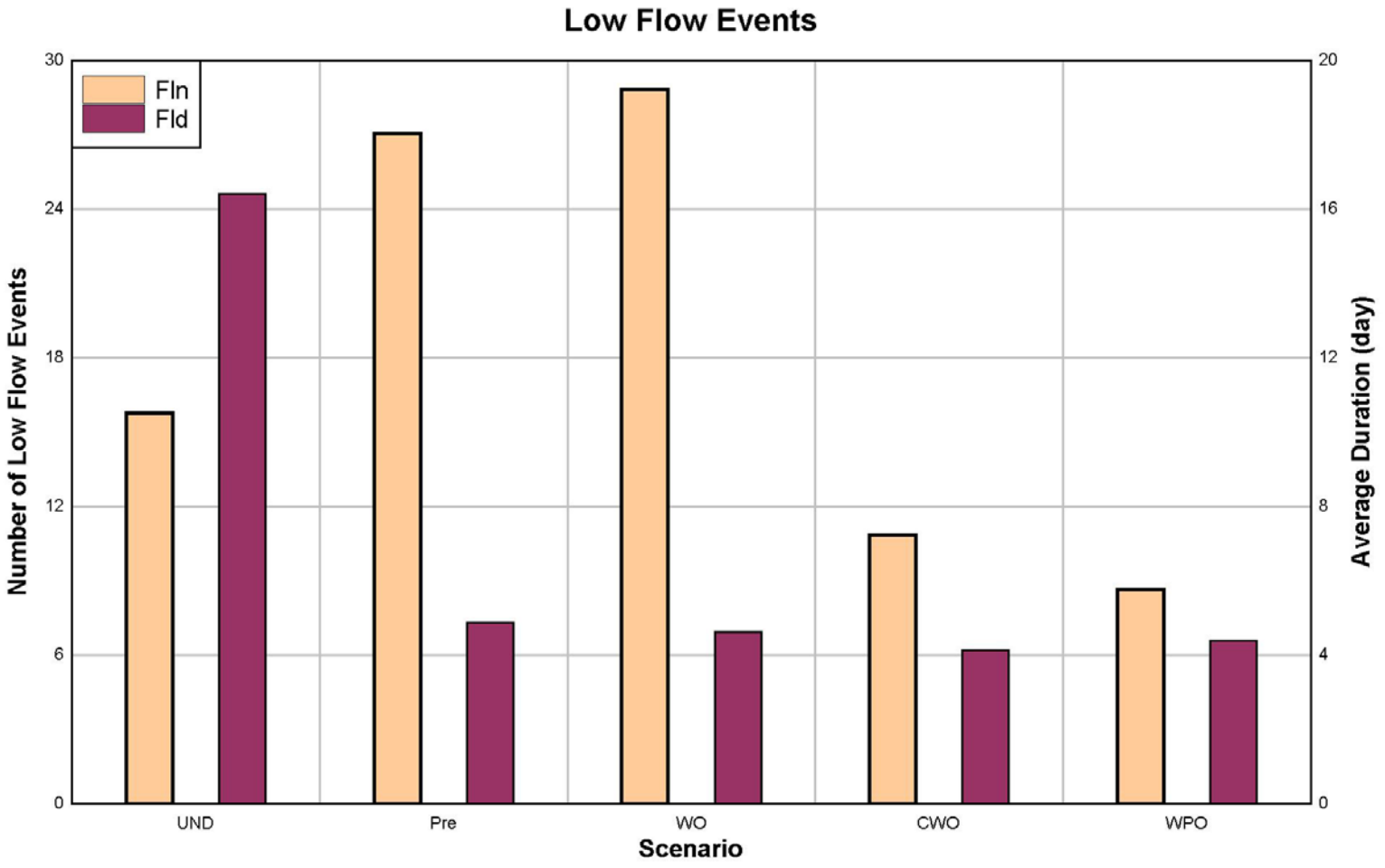


Impacts on Aquatic Life

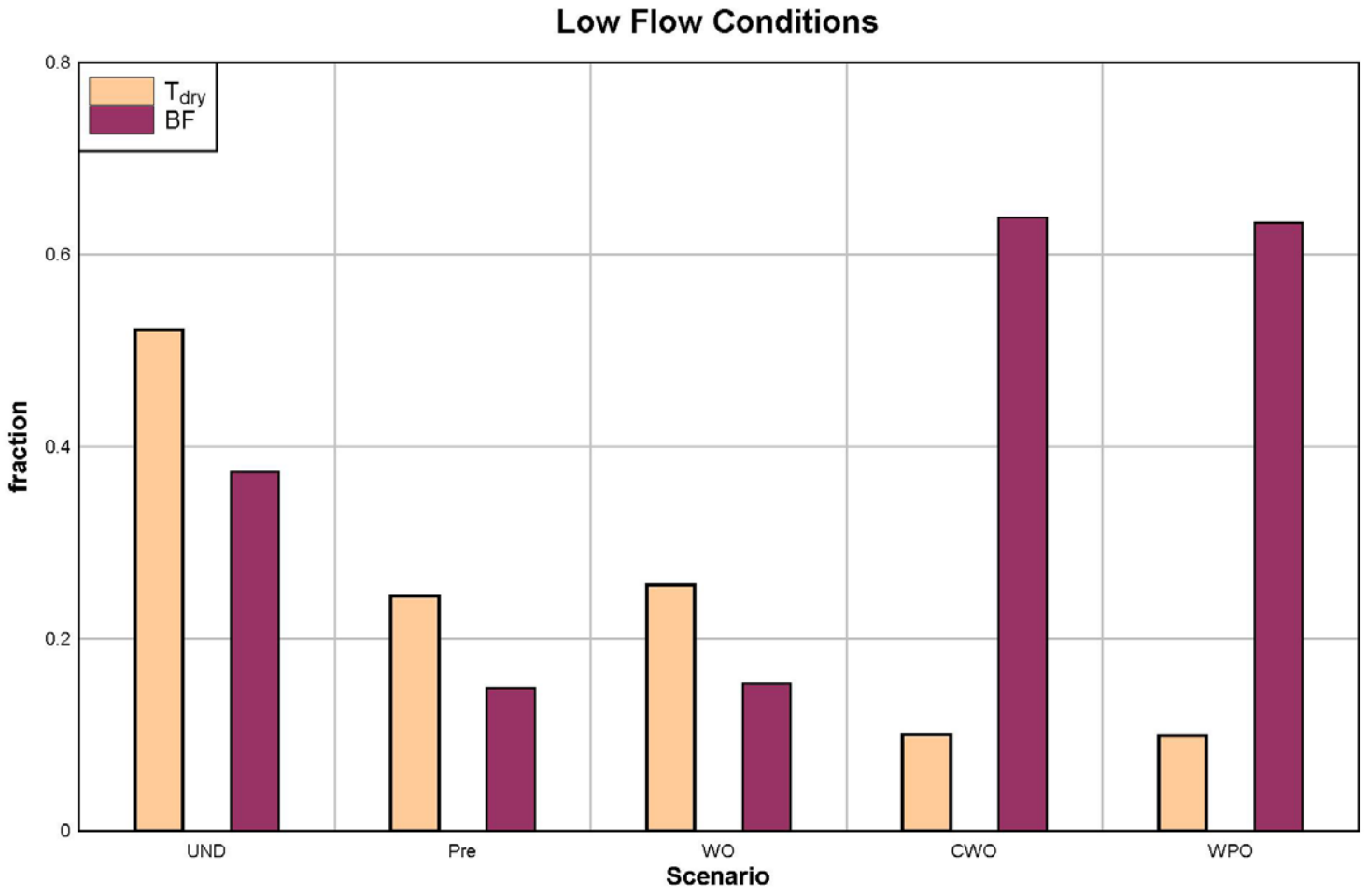
Changes in hydrology affect aquatic live in two ways

- Changes in the wet-dry cycle interrupting species life cycles
- Increased variability affecting habitat

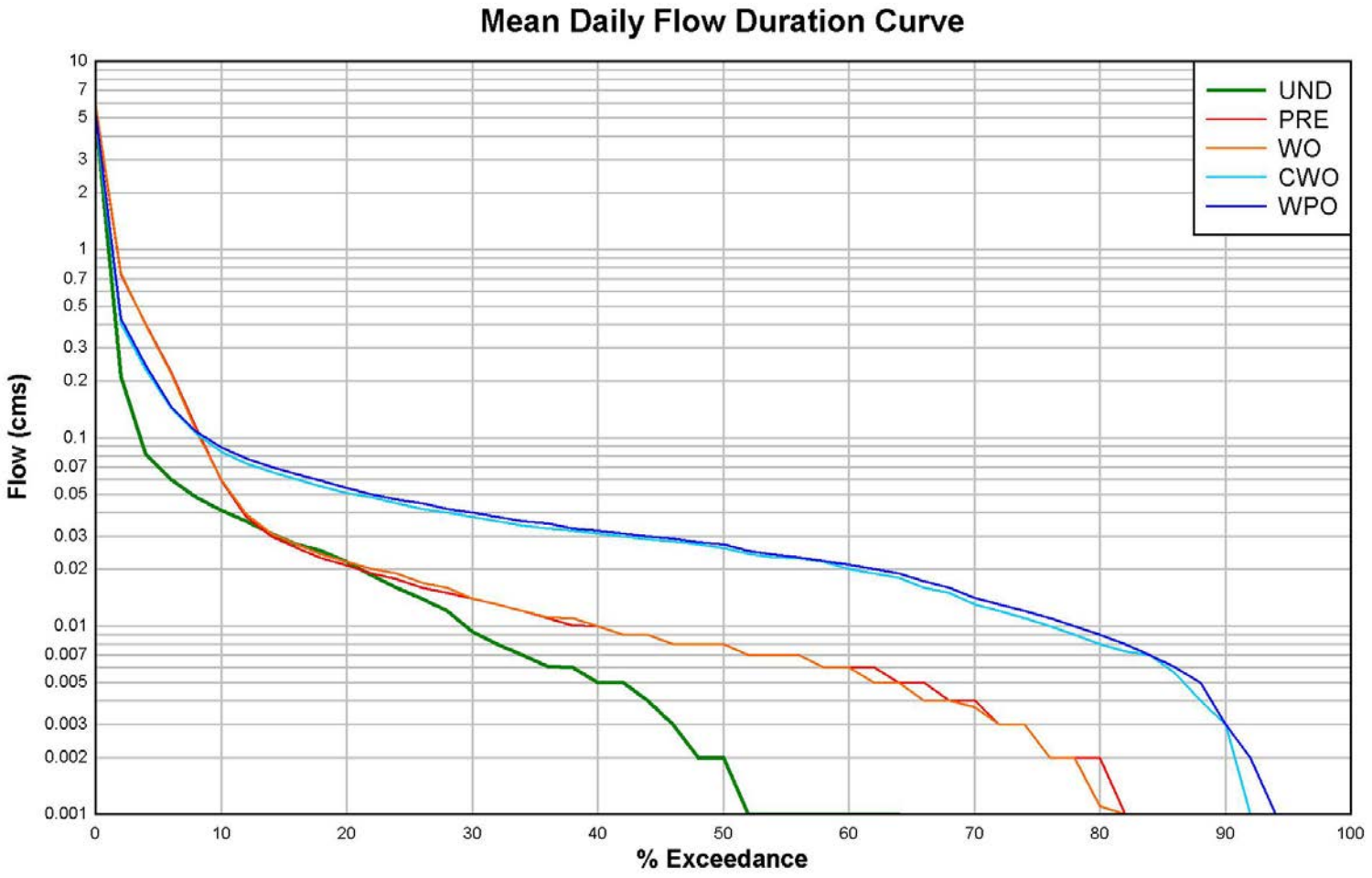
Impacts on Aquatic Life



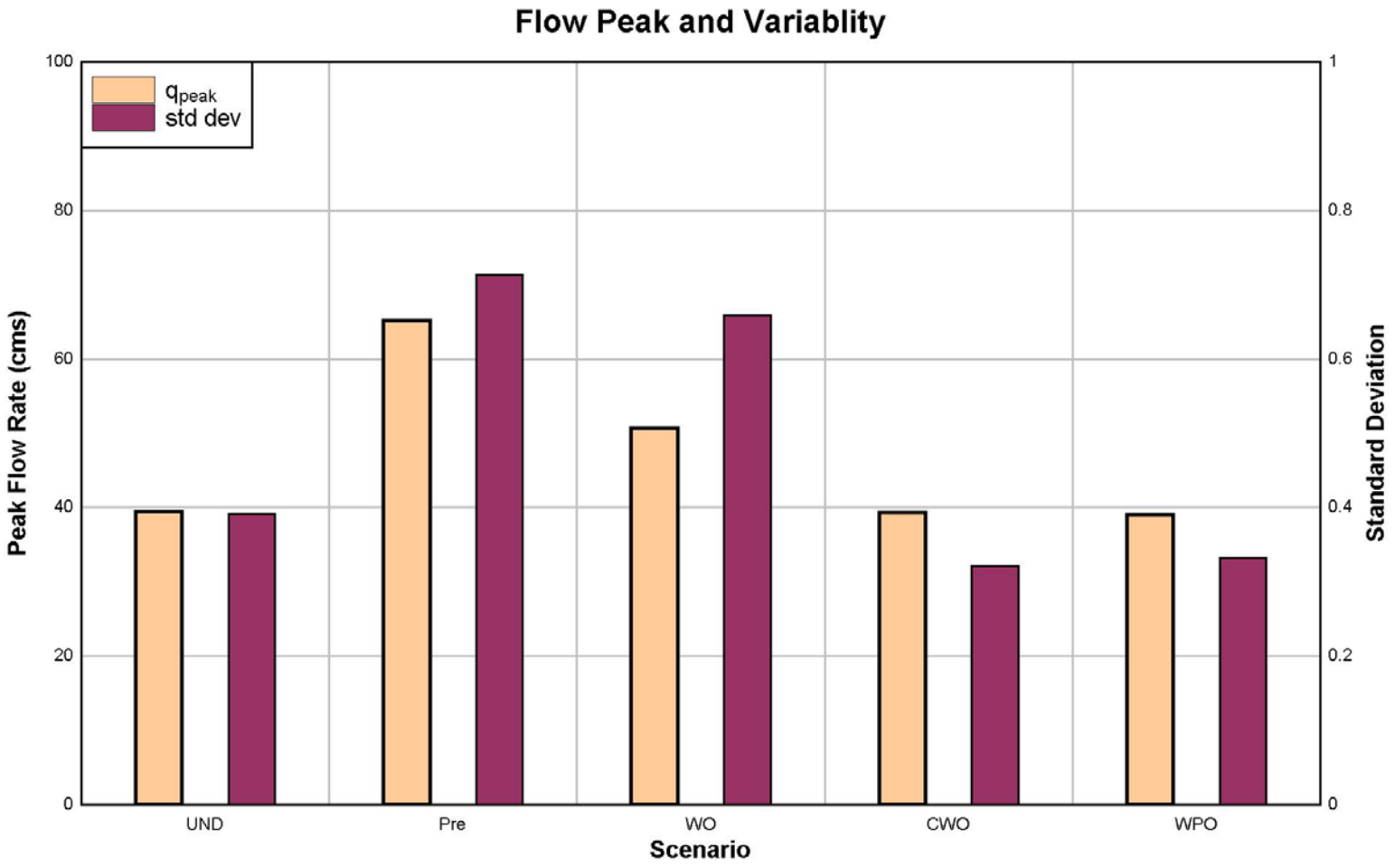
Impacts on Aquatic Life (cont.)



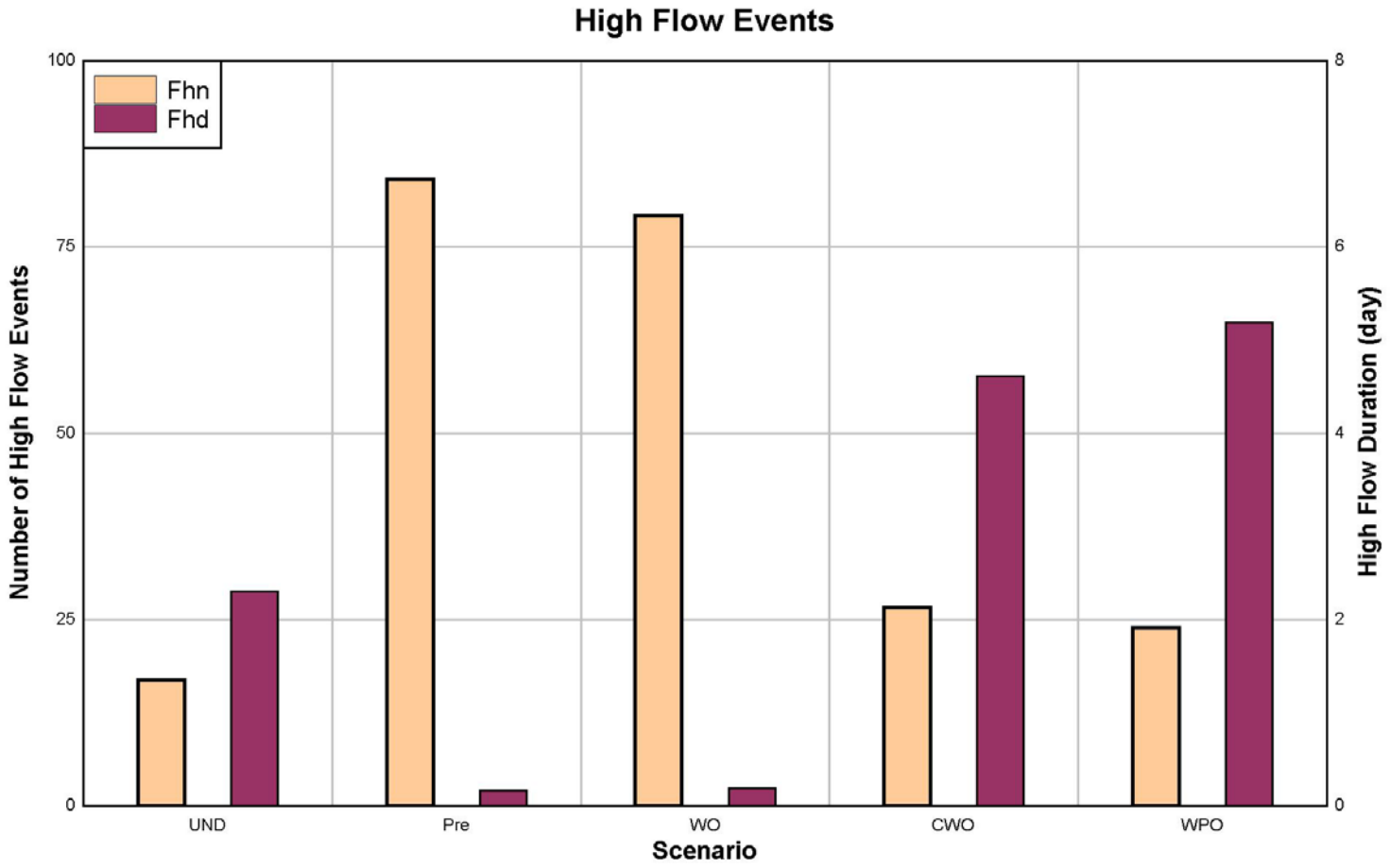
Impacts on Aquatic Life (cont.)



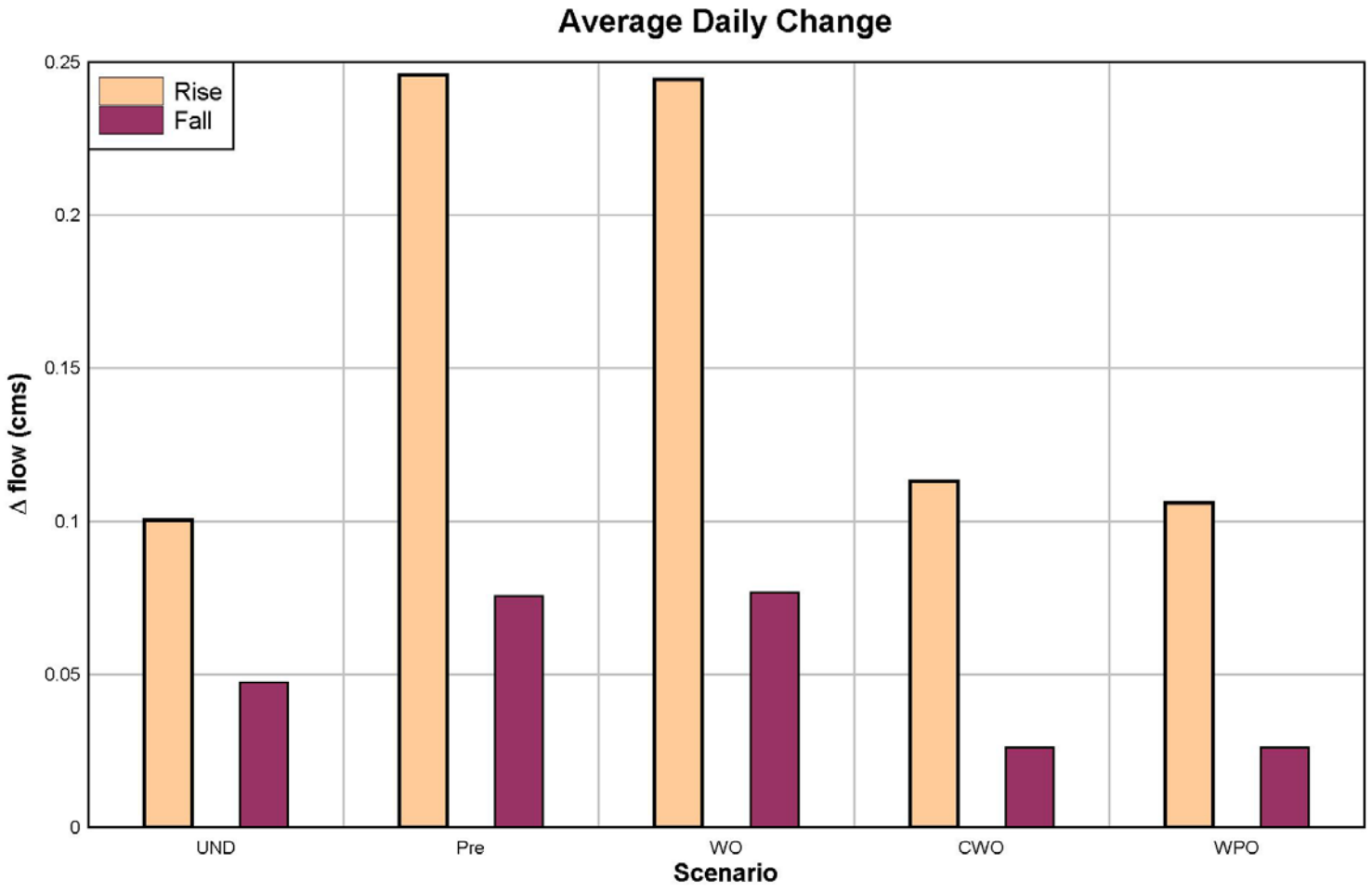
Impacts on Aquatic Life (cont.)



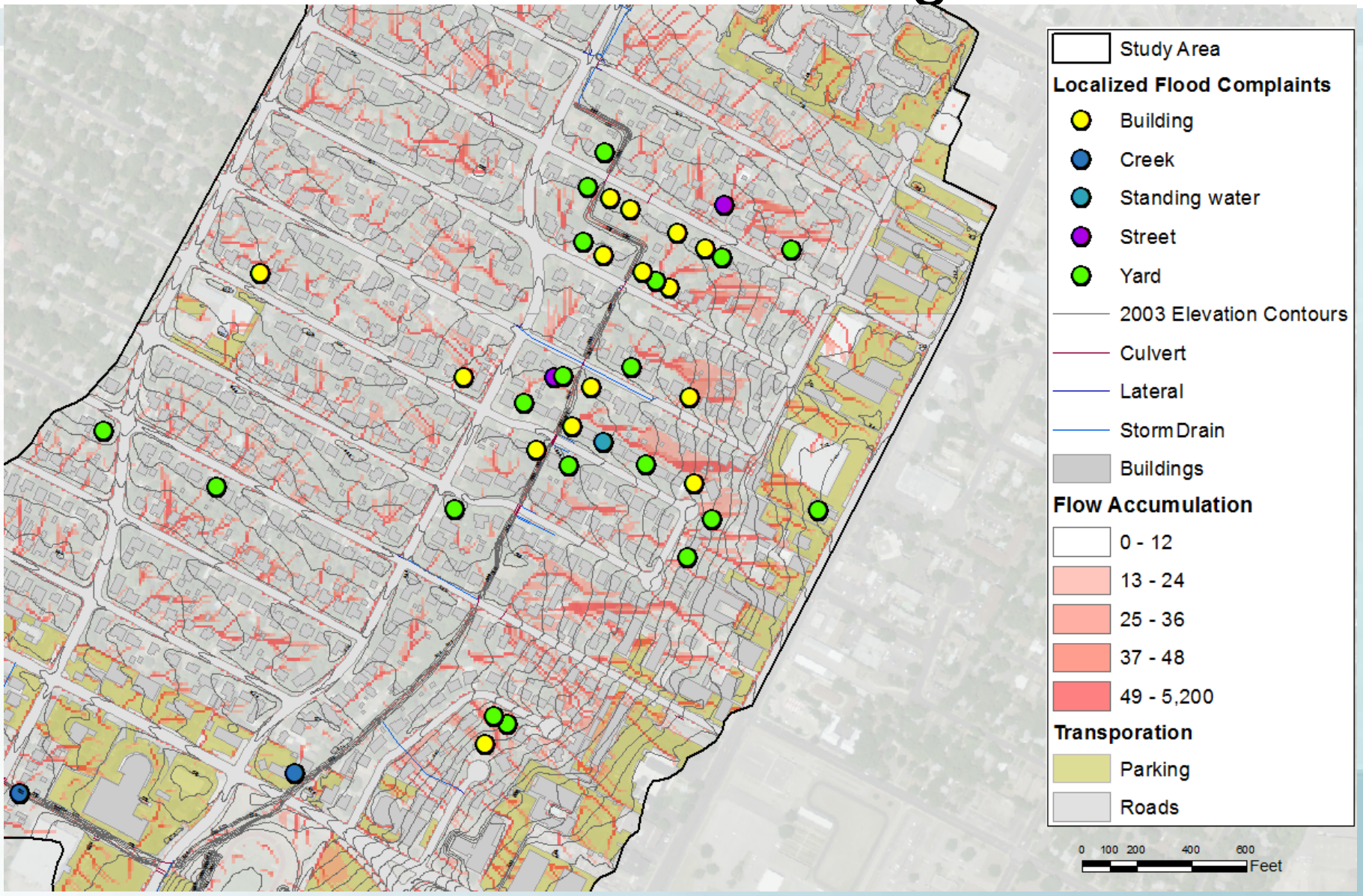
Impacts on Aquatic Life (cont.)



Impacts on Aquatic Life (cont.)

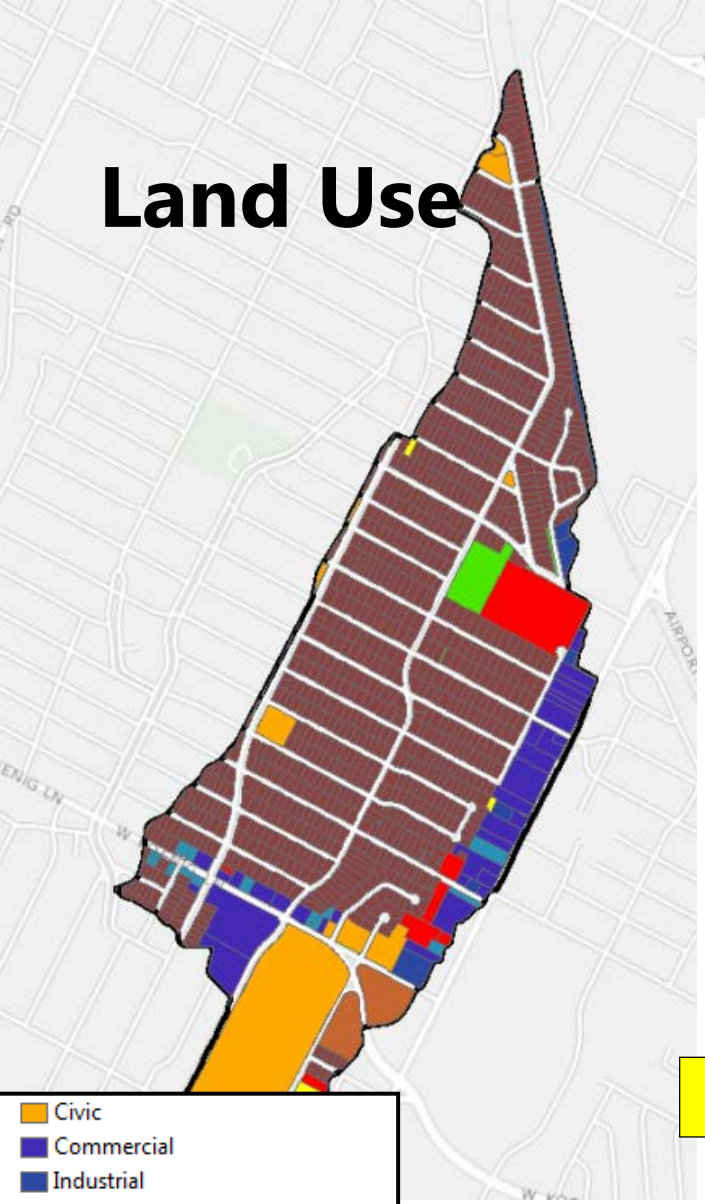


Brentwood Watershed, Austin, Texas with localized flooding

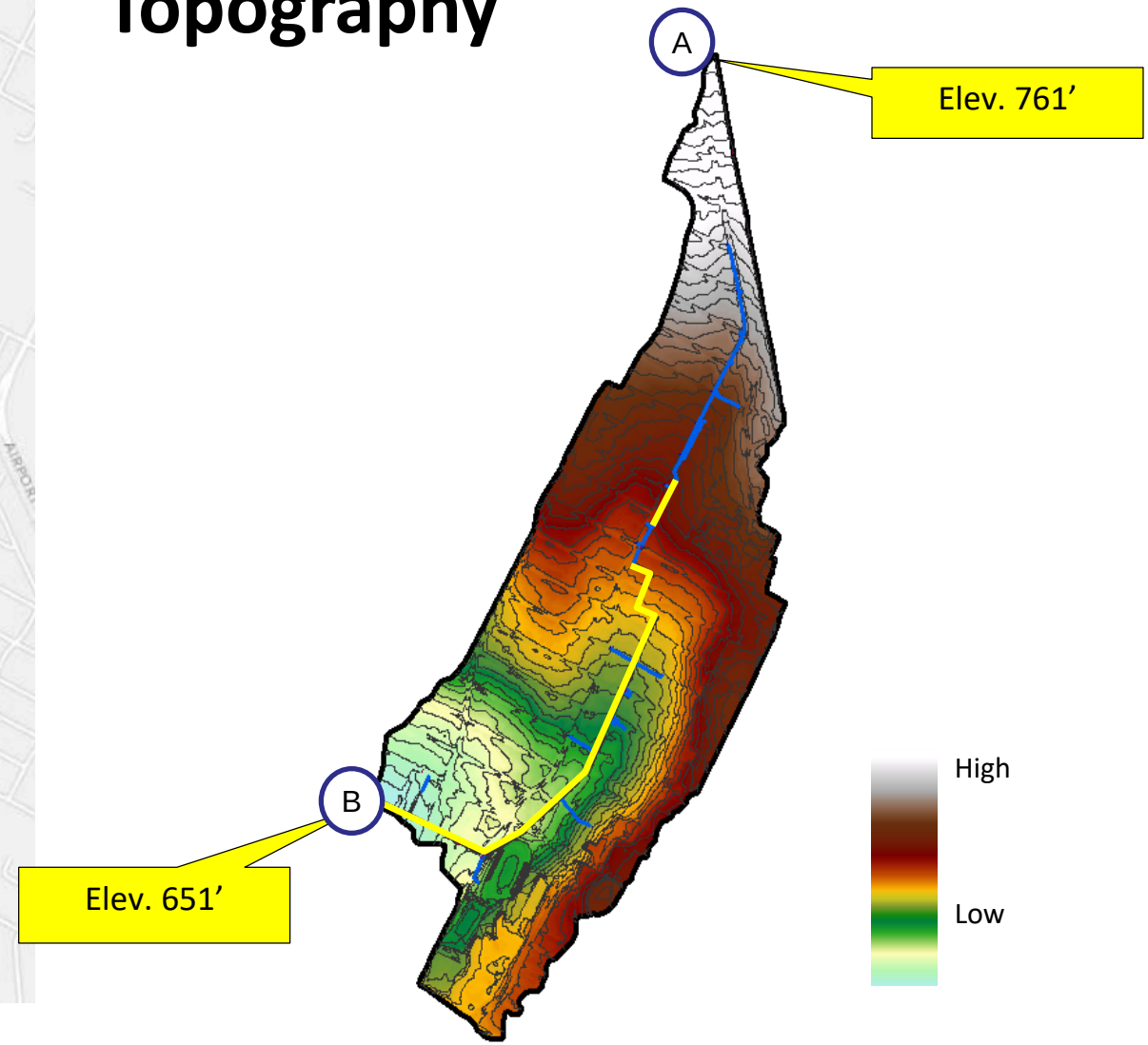


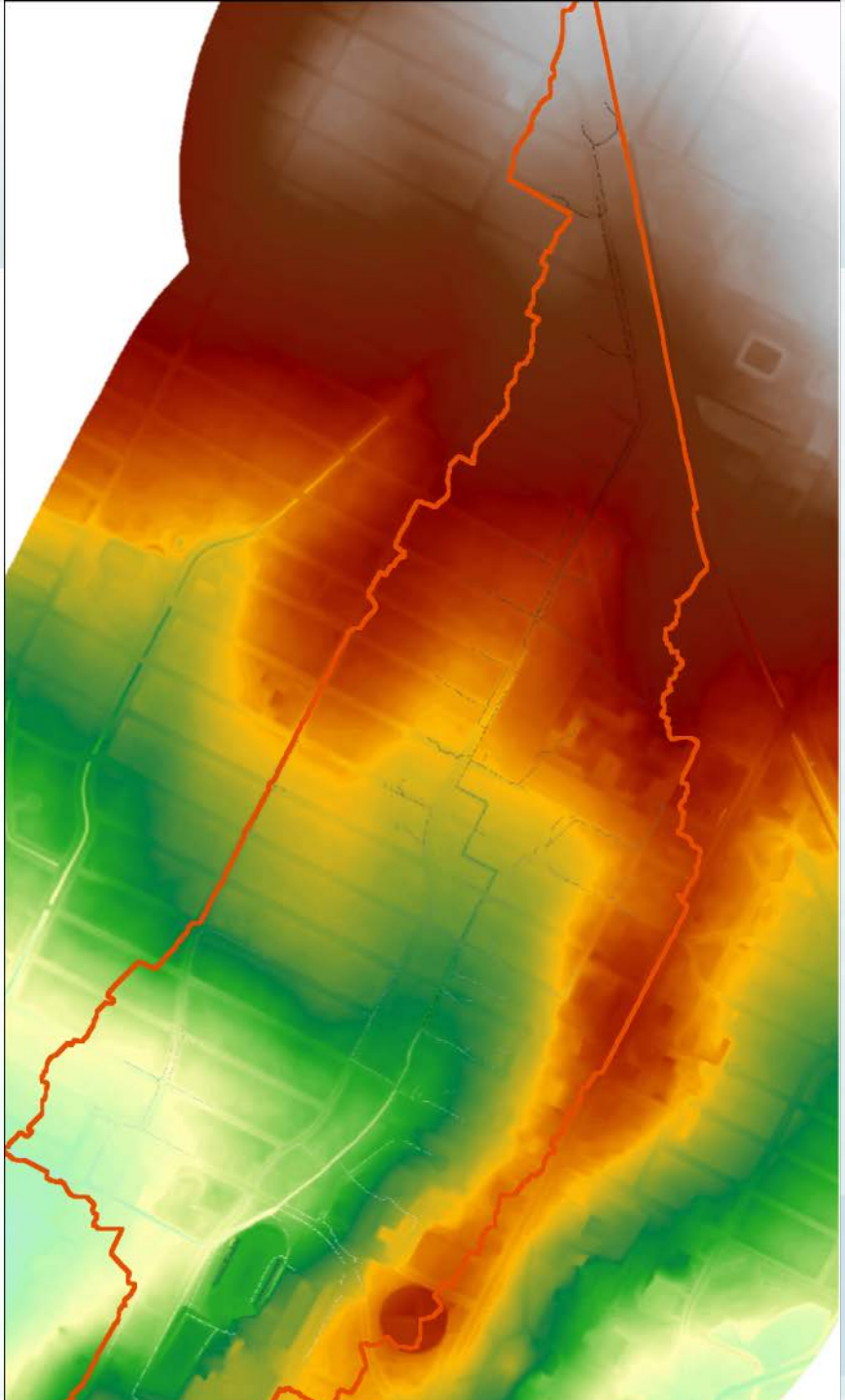

HOME

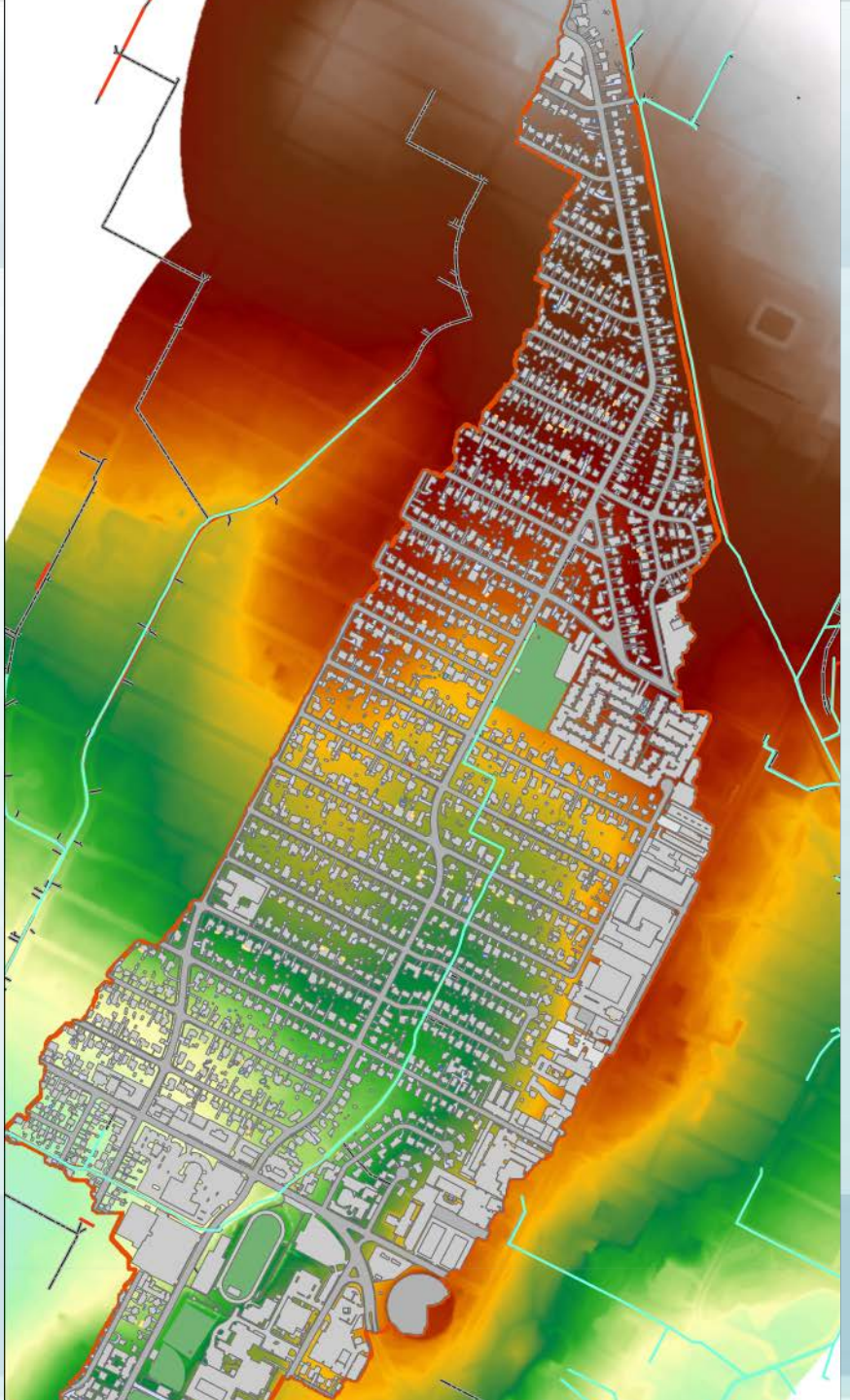
Land Use



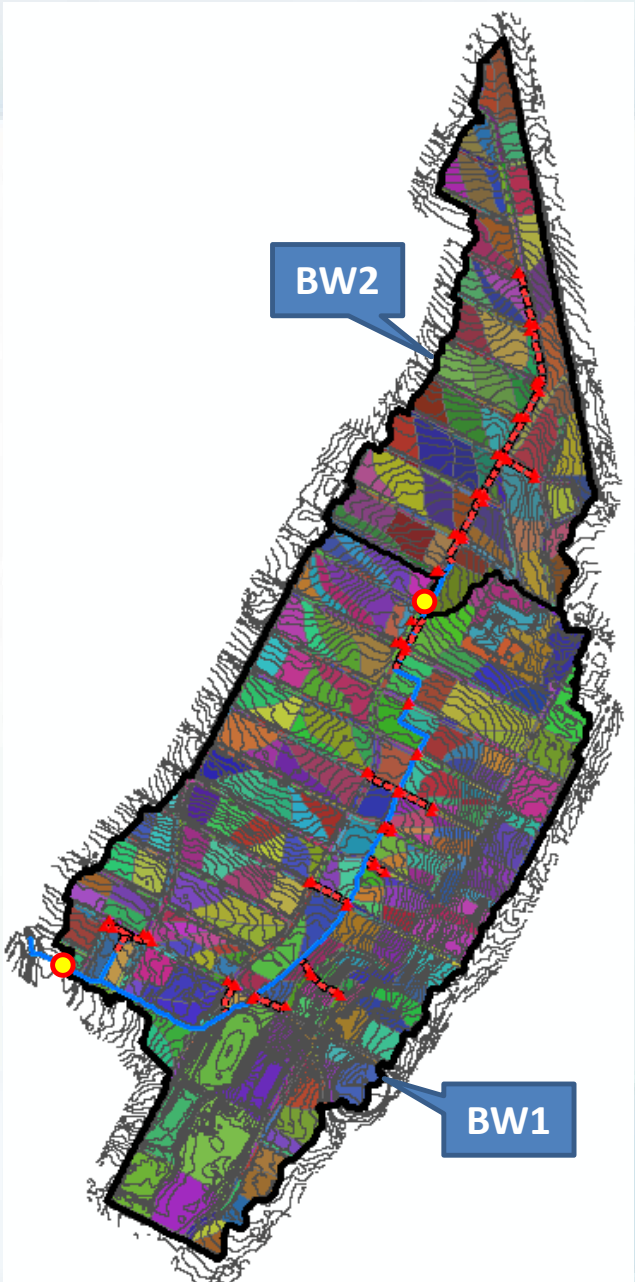
Topography







Catchment Delineations, Conveyance Pathways



Legend

- Monitoring Location
- Tributary Area to Monitoring Locations
- Contour Lines
- Open Channel
- Storm Drain Structure
- Subcatchment Delineations (various colors)

SWAT Model

	PCSWMM	SWAT
# Subcatchments	463	134
# HRUs		852

Model Representation of Existing Conditions

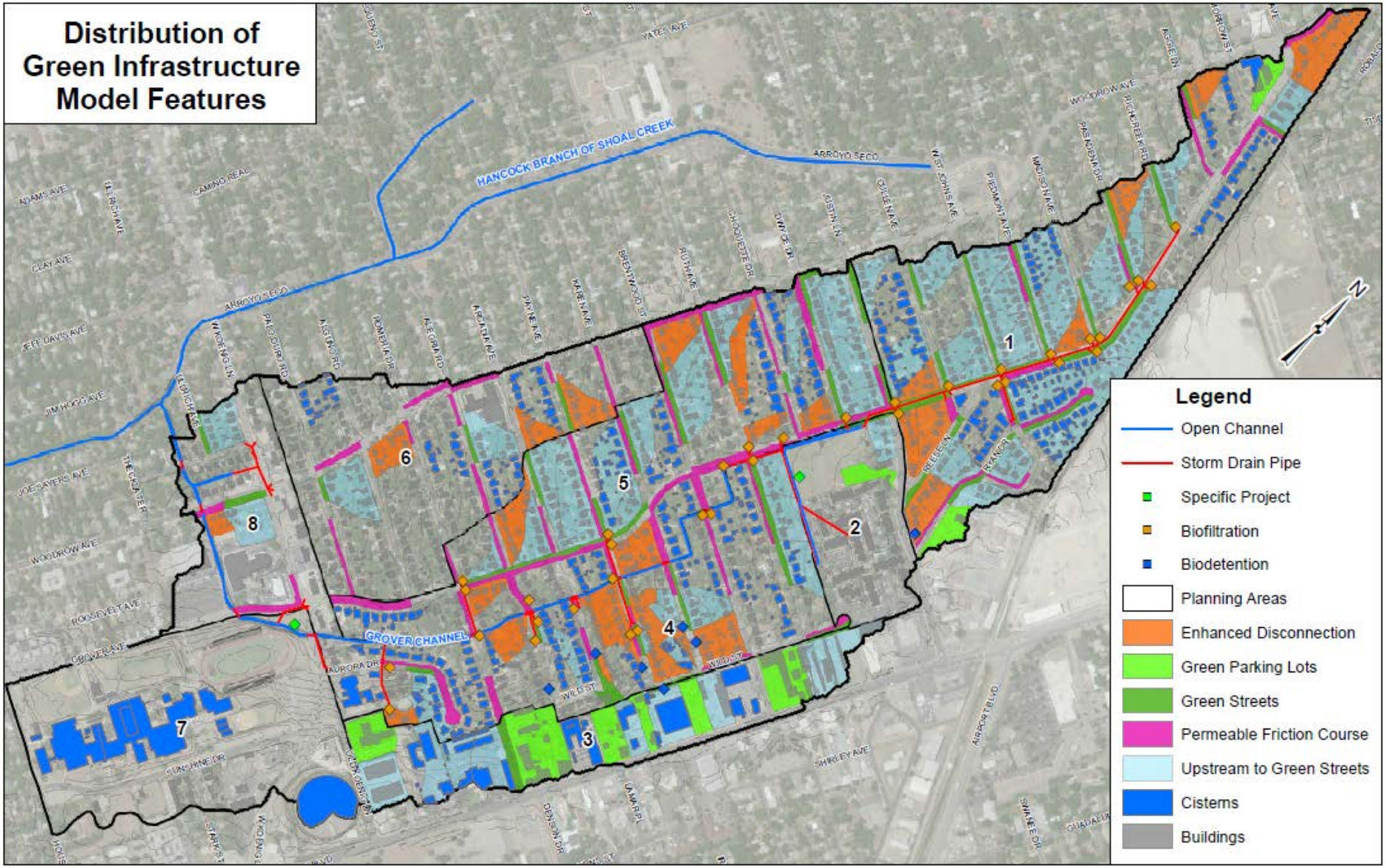
Calibration Statistic	Project Acceptable Target	PCSWMM	ArcSWAT
Overall NSE	>0.5	.73	0.75
PBIAS	±25	3.37	3.21
RSR	<=0.7	0.52	0.5
Percent Total Runoff		103%	93%

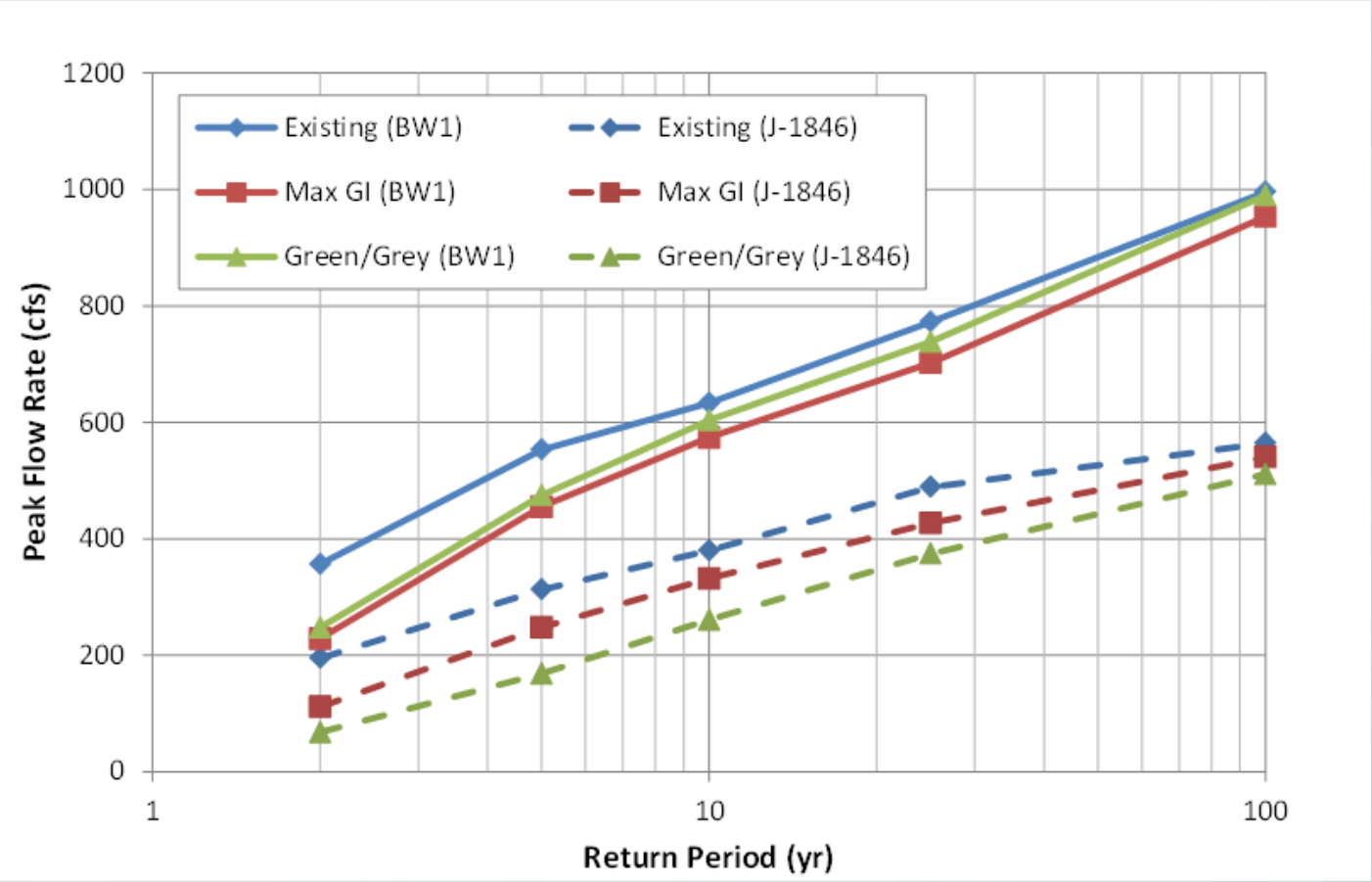
Watershed Protection
Development Review

Max Green Infrastructure

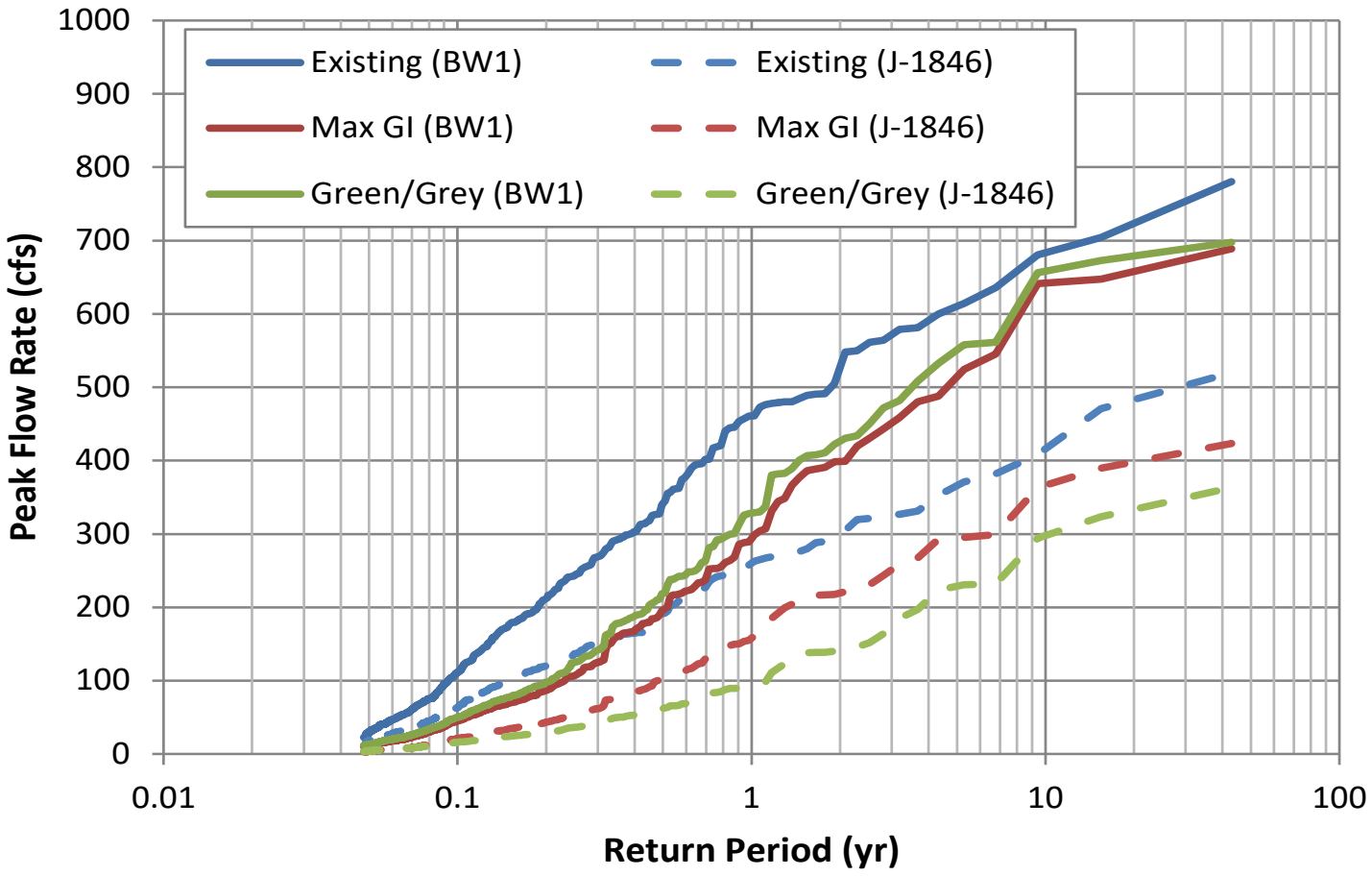
Feature	Summary	Approx. Footprint (ft^2)	Approx. Volume (ft^3)
Explicit Biofiltration	36 new biofiltration features located at existing storm drain inlets addressing over 150 acres	54,000	108,000
Explicit Biodetention	7 new biodetention features in strategic locations addressing approximately 18 acres	5,000	10,500
Lions Field Biodetention	Multi-stage storage and flow control addressing runoff from 8 acres	28,000	112,000
Channel Widening	New off-channel floodplain area	8,500	38,000
Green Streets	New green streets features addressing 111 total tributary acres, primarily in residential areas (approx. 100 individual features)	64,000	80,000
Green Parking Lots	New green parking lot features addressing 10 commercial/industrial lots	26,000	41,000
Residential Cisterns	New “shared use” cistern capacity (i.e., water conservation plus peak shaving) addressing 13 acres of roofs (approx. 370 homes)	16,000[1]	93,000
Non-Residential Cisterns and Blue Roofs	New detention-only cistern storage addressing 16 commercial/industrial/multi-family lots	15,000[1]	85,000
Residential Enhanced Disconnects	10 acres of decompaction and soil amendments receiving flow from 4.8 acres of impervious cover (approx. 120 lots)	450,000	73,000
Permeable Friction Course	Overlay of 18 acres of street	NA	NA
	Total	666,500	640,500

Distribution of Green Infrastructure Model Features



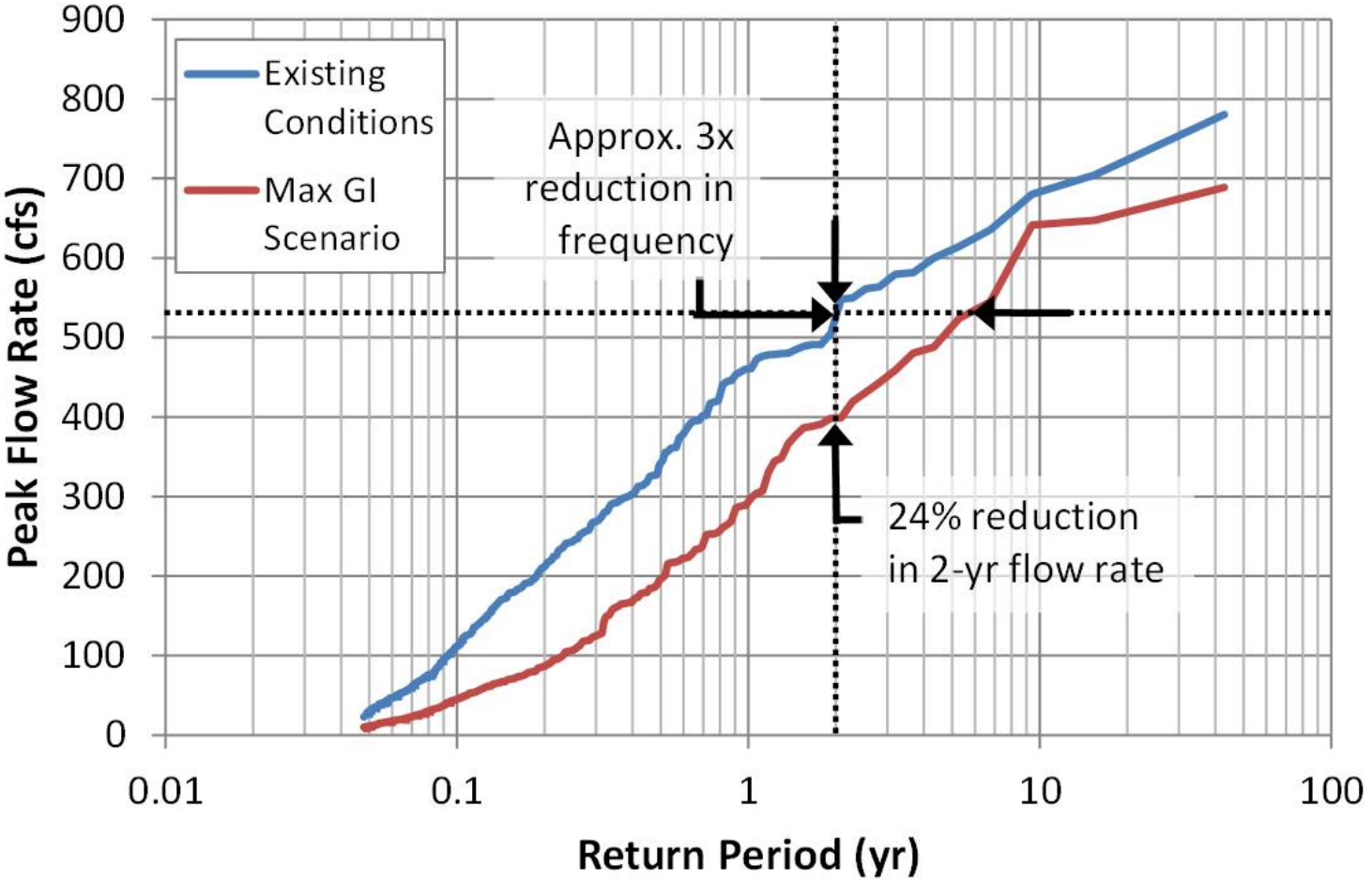


1D Design Storm Peak Flow Rates at Watershed Outlet (BW1) and Interior Node (J-1846 in Channel North of Arcadia Ave)

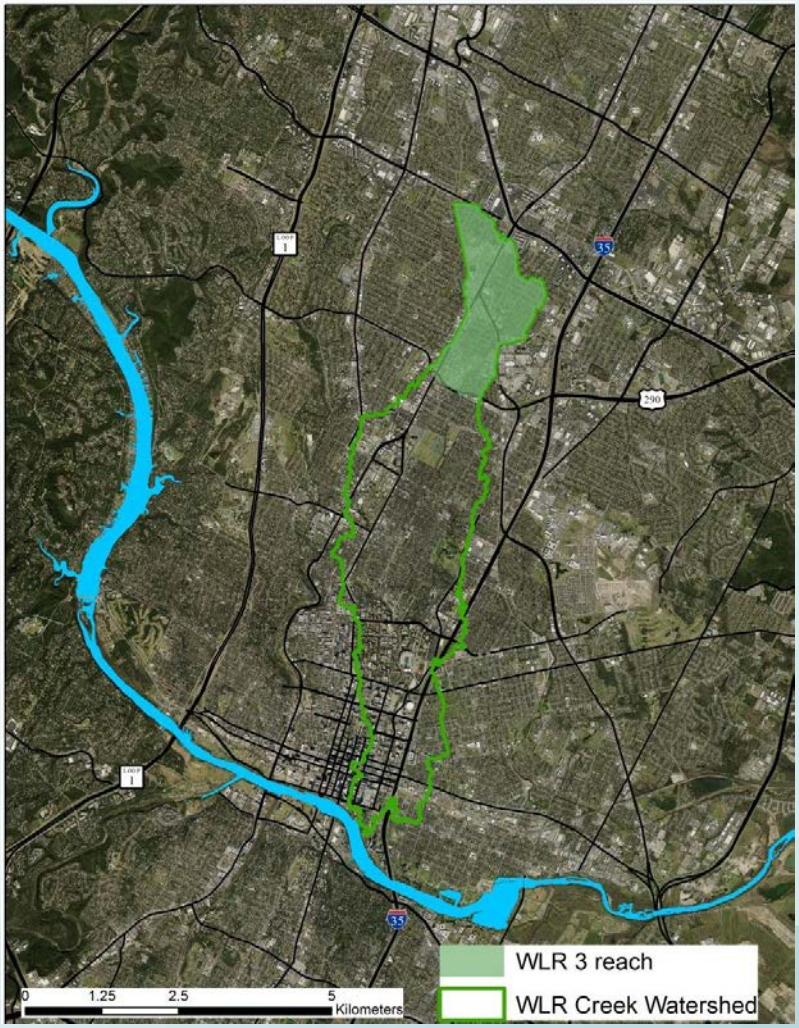


1D Continuous Simulation Peak Flow Rates at Watershed Outlet (BW1) and Interior Node (J-1846 in Channel North of Arcadia Ave)

Peak Flow vs. Return Period at Station BW1



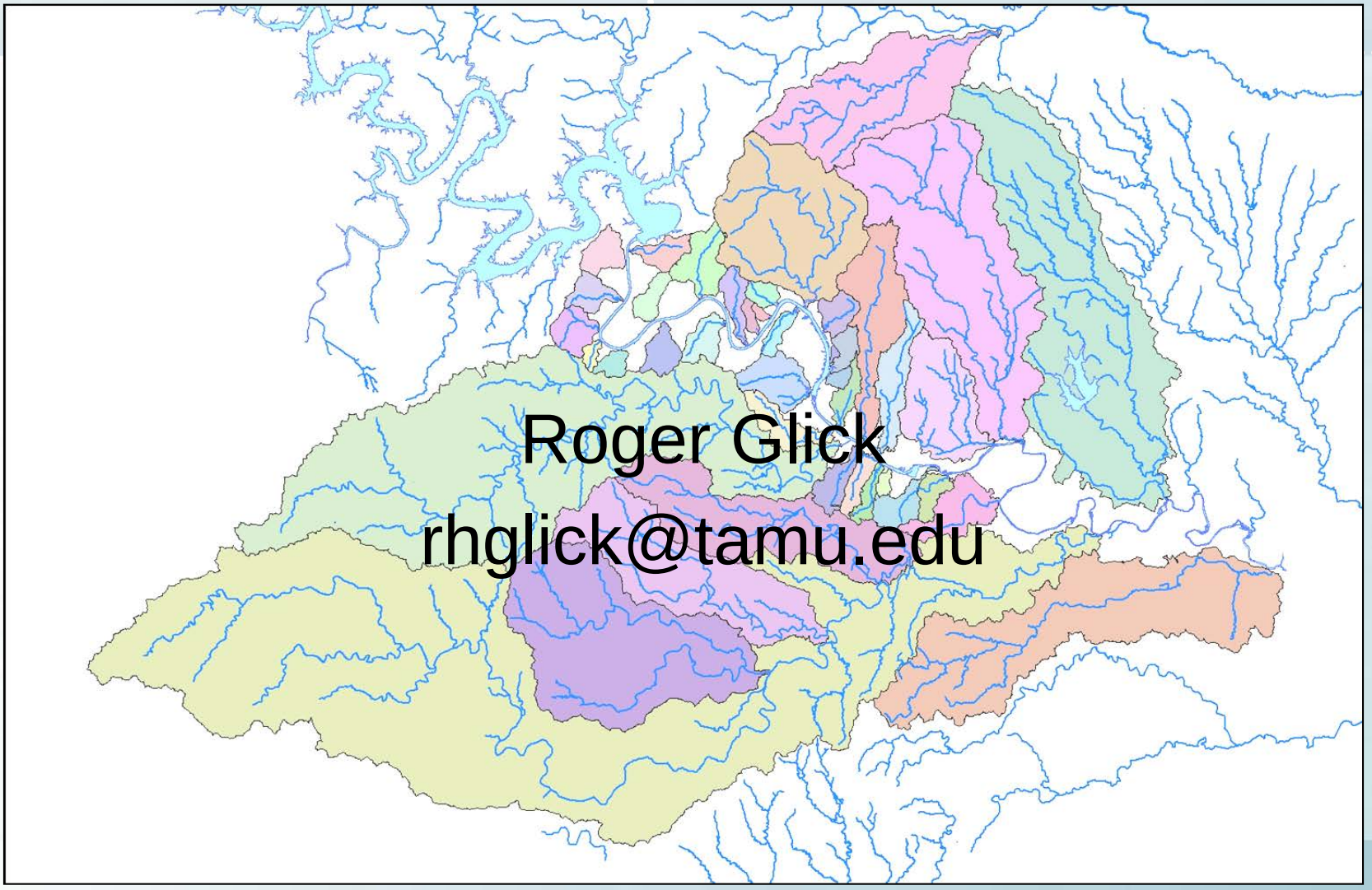
Study Area – Waller Creek



Project Background

- Limited space for traditional controls
- Preliminary results show widespread use of LID can improve hydrology
- Comparing cost/benefit with traditional controls
- Study on going

Questions?



Roger Glick

rhglick@tamu.edu