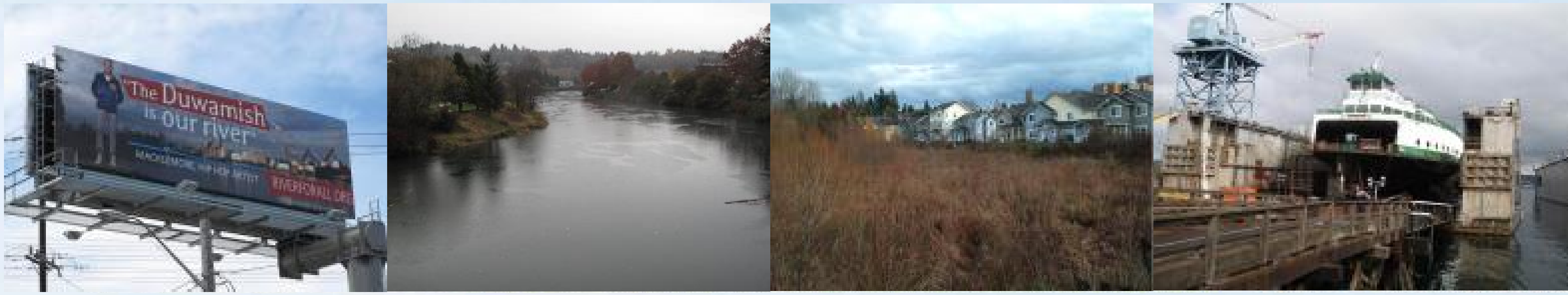
Green/Duwamish River Watershed



Pollutant Loading Assessment: Calibration of Watershed Model for Flow

Technical Advisory Committee Meeting
March 15, 2017

DEPARTMENT OF ECOLOGY
State of Washington

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

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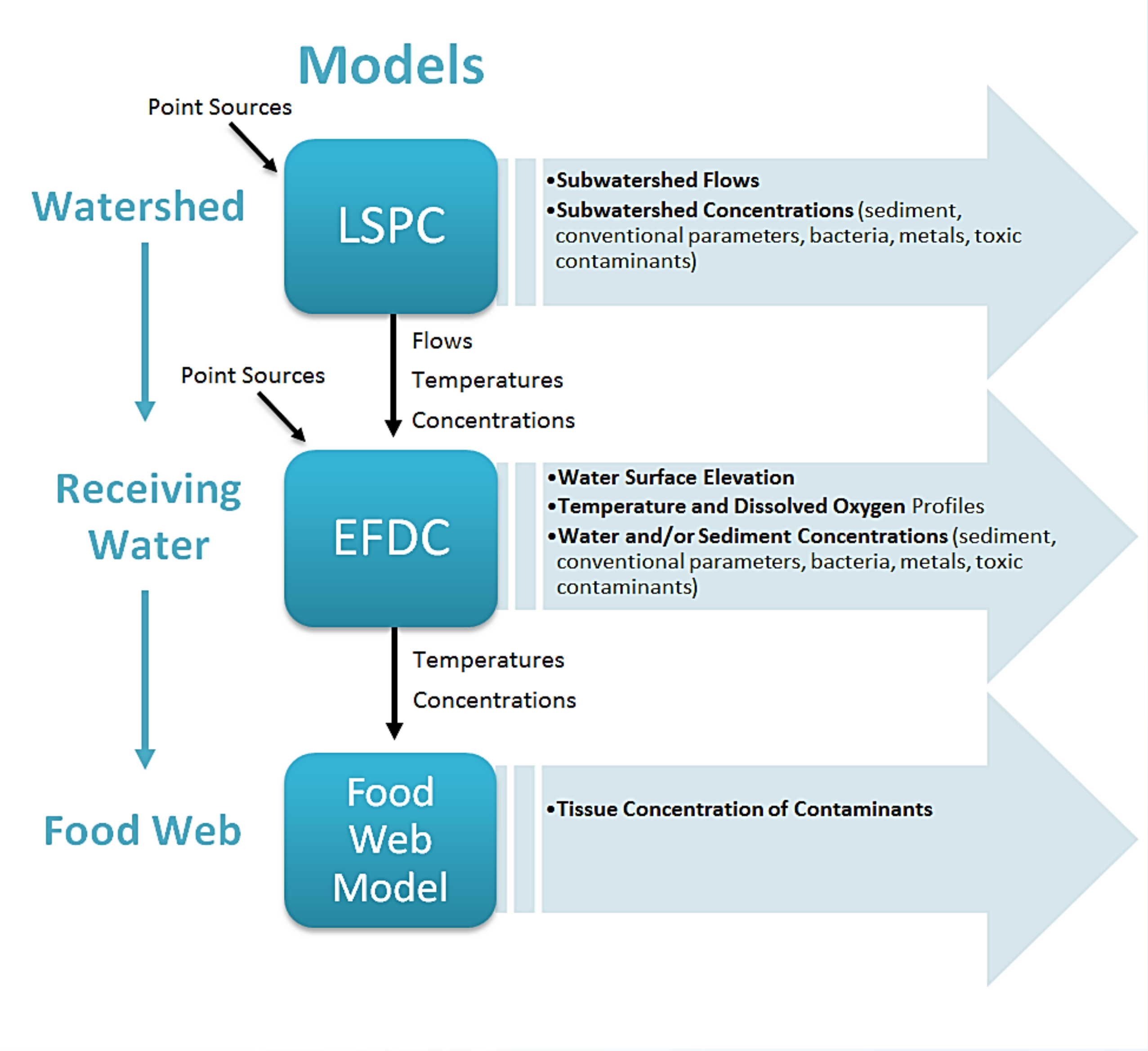
Where we are:

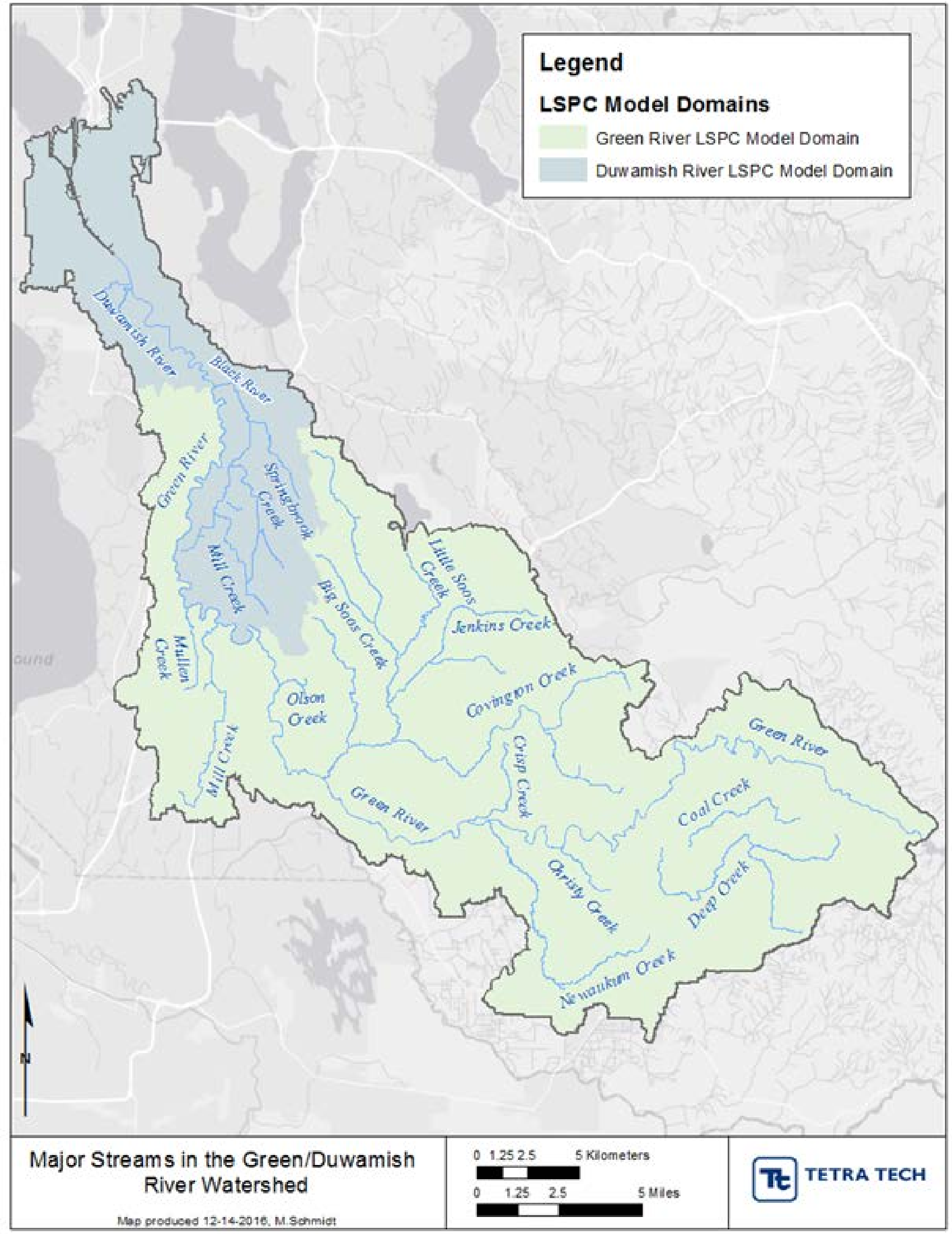
- Previous TAC meeting (10/5//2016) presented the setup and development of LSPC model for watershed hydrology
- Hydrology calibration completed
- Submitted Model Documentation Report for EPA/Ecology review on 12/26/16
- Responded to comments and produced revision for TAC review and comment

LSPC Watershed Model

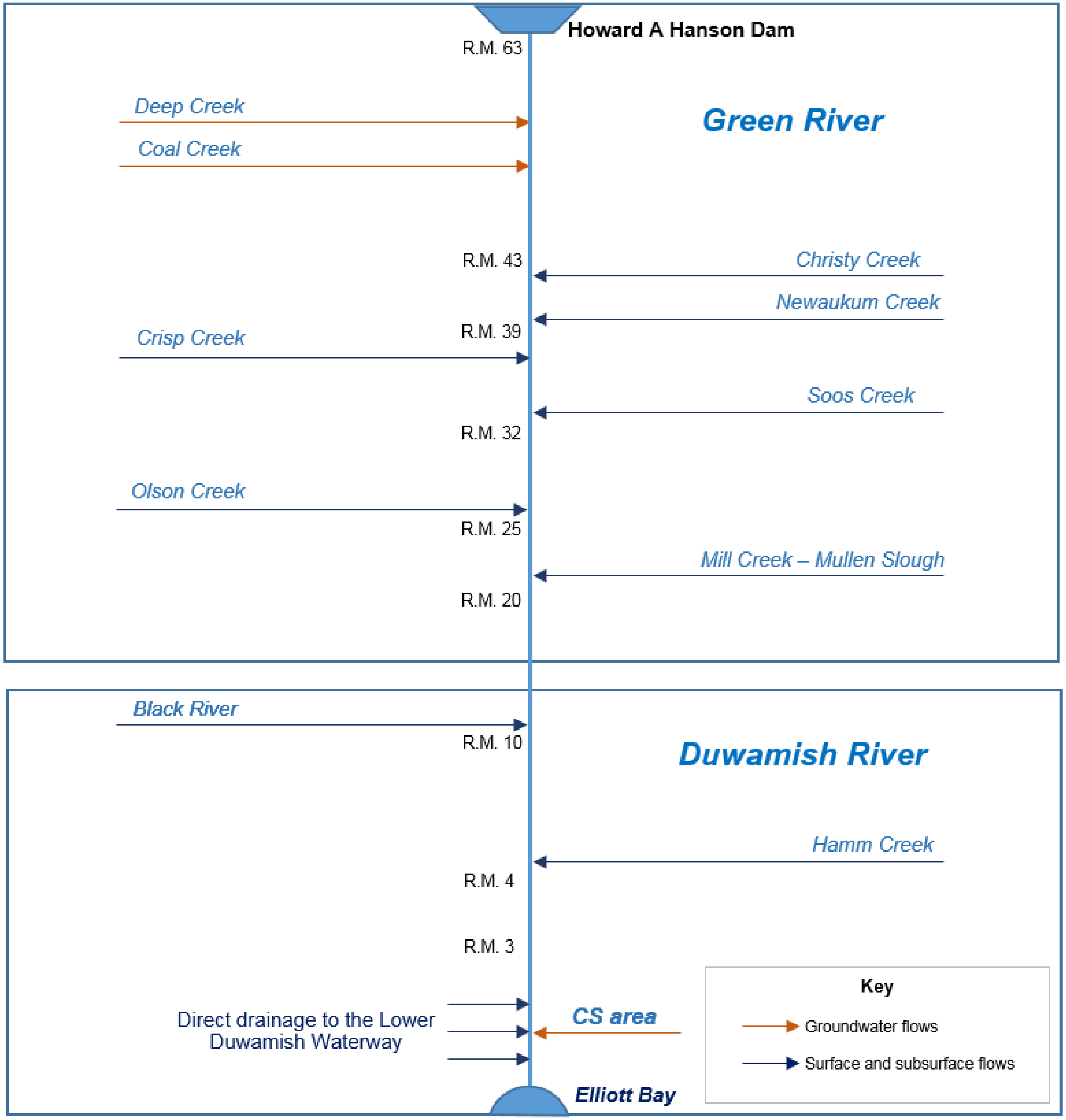


Model Domain

- From Howard A. Hanson Dam (protected watershed) to mouth of LDW at Elliott Bay in Seattle
- Two linked LSPC models

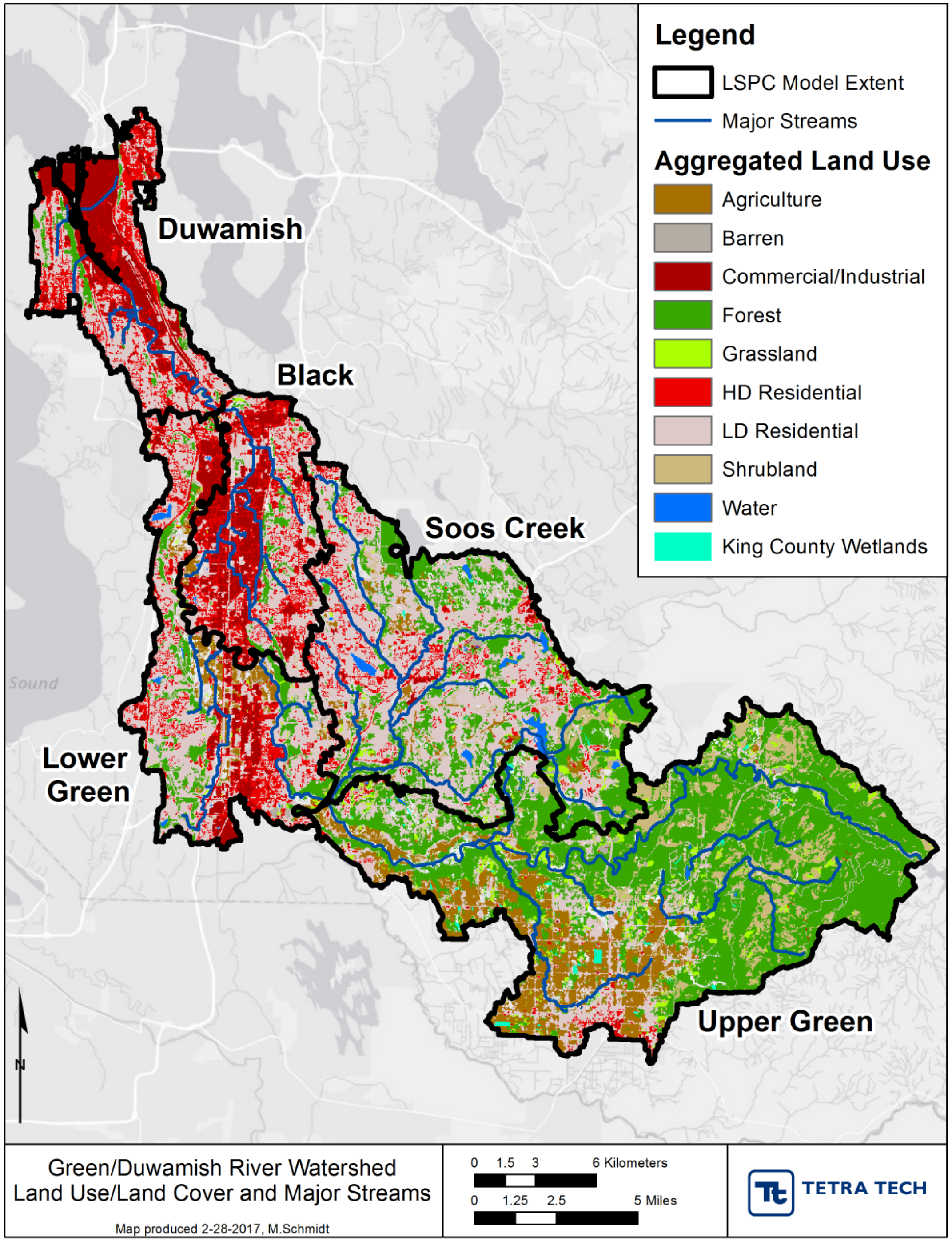


Linked Models



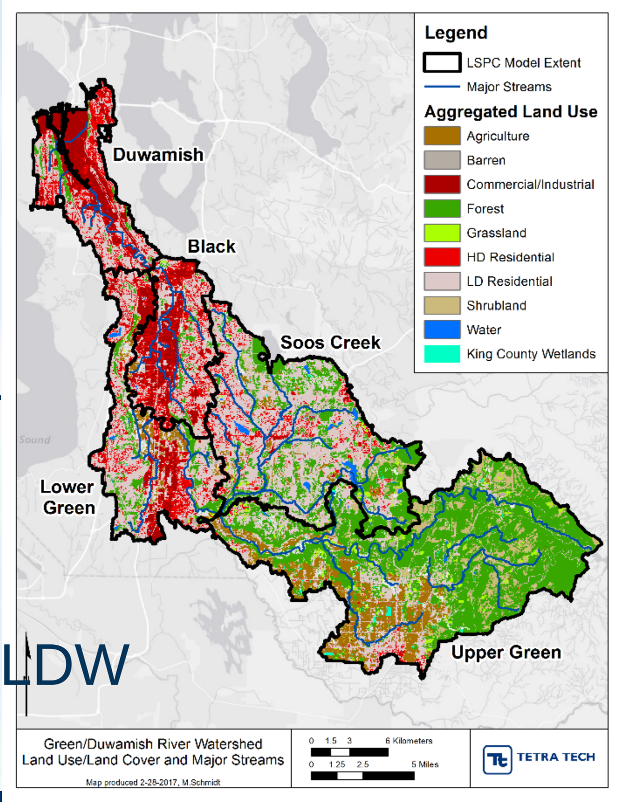
Notes: Not to scale. River Mile zero is defined at the southern tip of Harbor Island

Five Sections of the Watershed



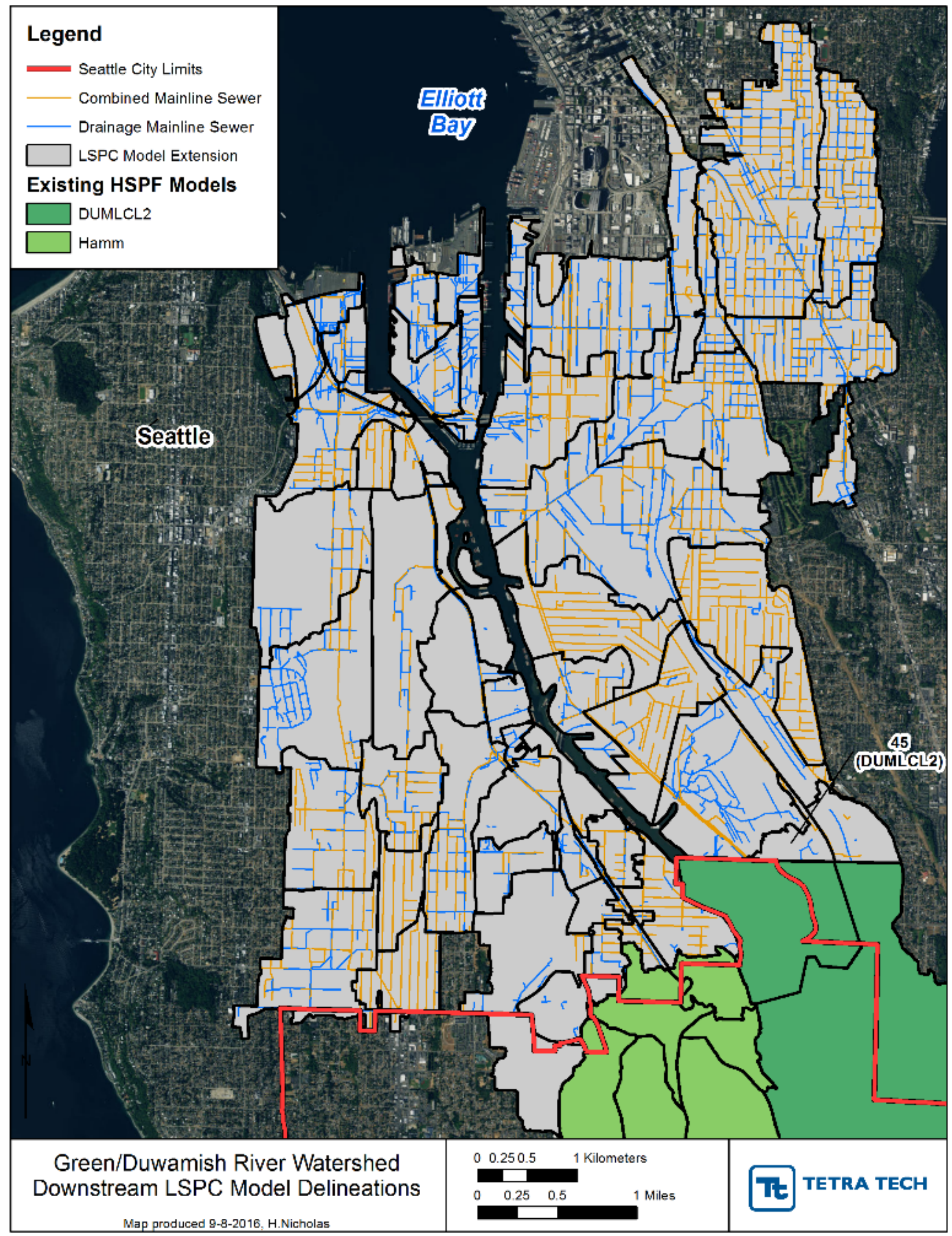
Five Sections of Watershed

1. Upper Green River, Howard Hanson Dam to Soos Crk
   - Largely rural (steep forest, ag near Newaukum)
   - Tacoma diversion
   - Disconnected drainages
2. Soos Creek
   - Low density residential and rural
   - Extensive groundwater interactions
3. Lower Green and 4. Black River
   - High density development on valley floor
   - Cities of Auburn and Kent
5. Duwamish River
   - Grading to ultra-urban in Seattle around LDW
   - Combined storm-sewer areas



Seattle Drainage

- Not in previous models
- Use SPU drainage basins, sewer lines and SWMM models
- Includes combined sewer areas, as they may contribute groundwater flow to LDW
- Surface runoff in combined area only contributes to LDW during CSO events



LSPC Calibration Strategy

- Start from King Co. WRIA9 HSPF model parameters – adjust within recommended ranges
- Strive for consistent set of upland parameters that vary according to soils and land use/cover (avoid over fitting)
- Calibrate to multiple objectives to ensure robust fit
  - Reasonable water balance
  - Replicate satellite-based evapotranspiration estimates
  - Calibrate to flow gaging
    - Fit to multiple gages simultaneously
    - Evaluate statistics on annual and seasonal volume error
    - Evaluate fit to flow distribution (high, low)
    - Evaluate fit to flow pattern (NSE)

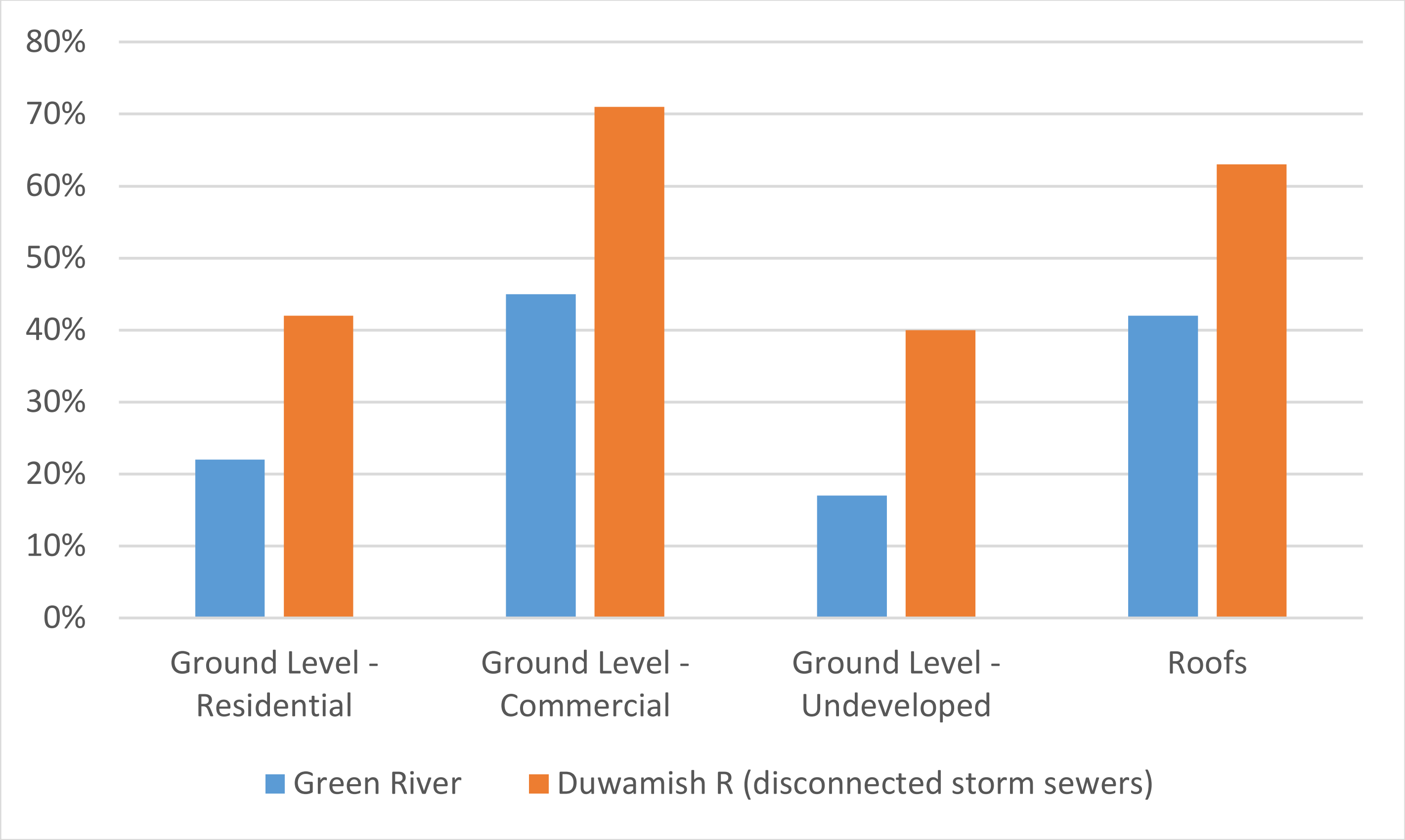
Effective Impervious Area (EIA)

- The fraction of impervious area that contributes flow directly to stream rather than flowing on to pervious surfaces or being retained
- Related to (but not the same as) directly connected impervious area
- Regional equations available, but WRIA 9 effort found need to significantly reduce EIA in calibration
- We proposed to better resolve issue from detailed local stormwater conveyance models – but local models have not been made available

Effective Fraction of Impervious Area (Ef)

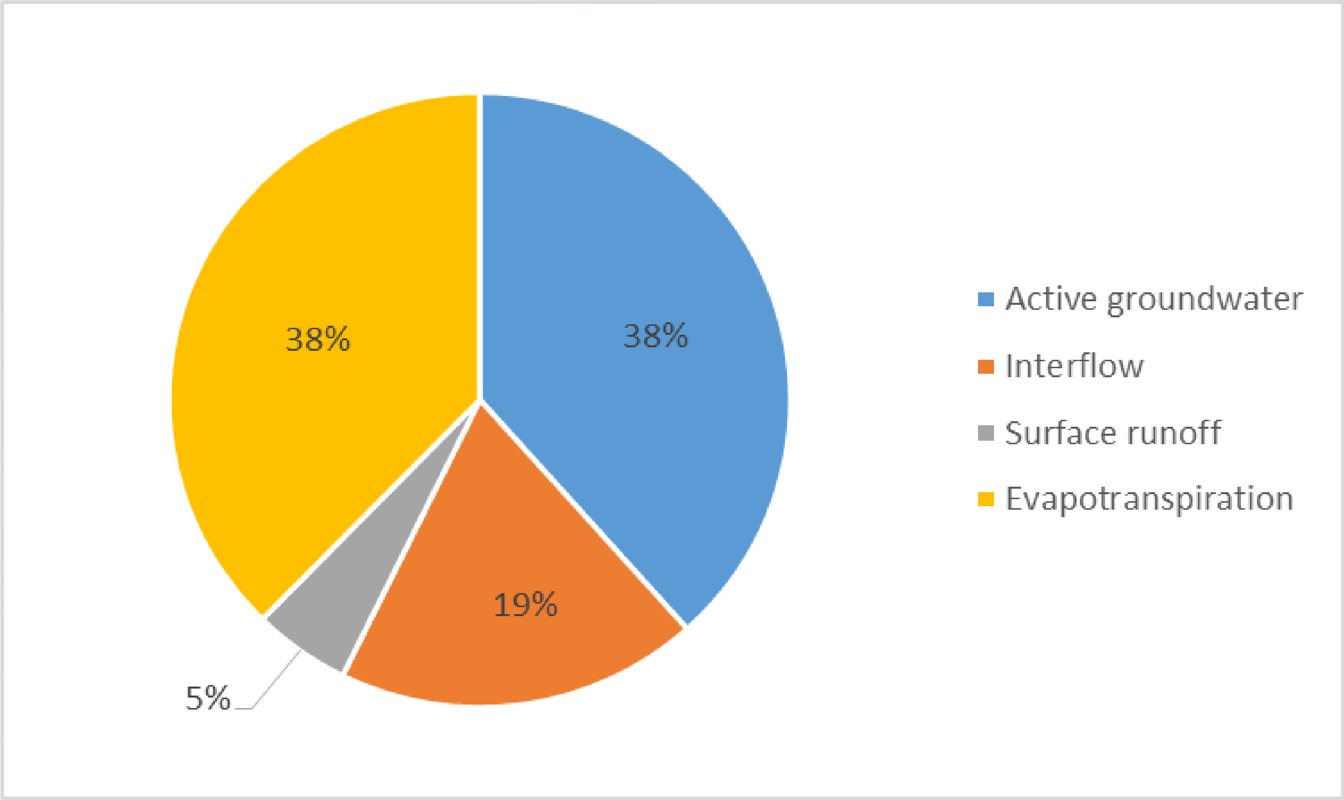
- WRIA9 estimates not directly applicable:
  - Based on different impervious coverage
  - Calibrated to different time period
- Our application also required calibration reduction of Ef to match gaged flows
- Sensitivity analysis to Ef provided in report
  - Area for potential improvement with detailed studies
  - See advanced analysis approach documented by Ebrahimian et al. (2016) based on regression against hydrograph in small-scale watersheds with limited exchange between stream and aquifer

Effective Fraction of Impervious Area



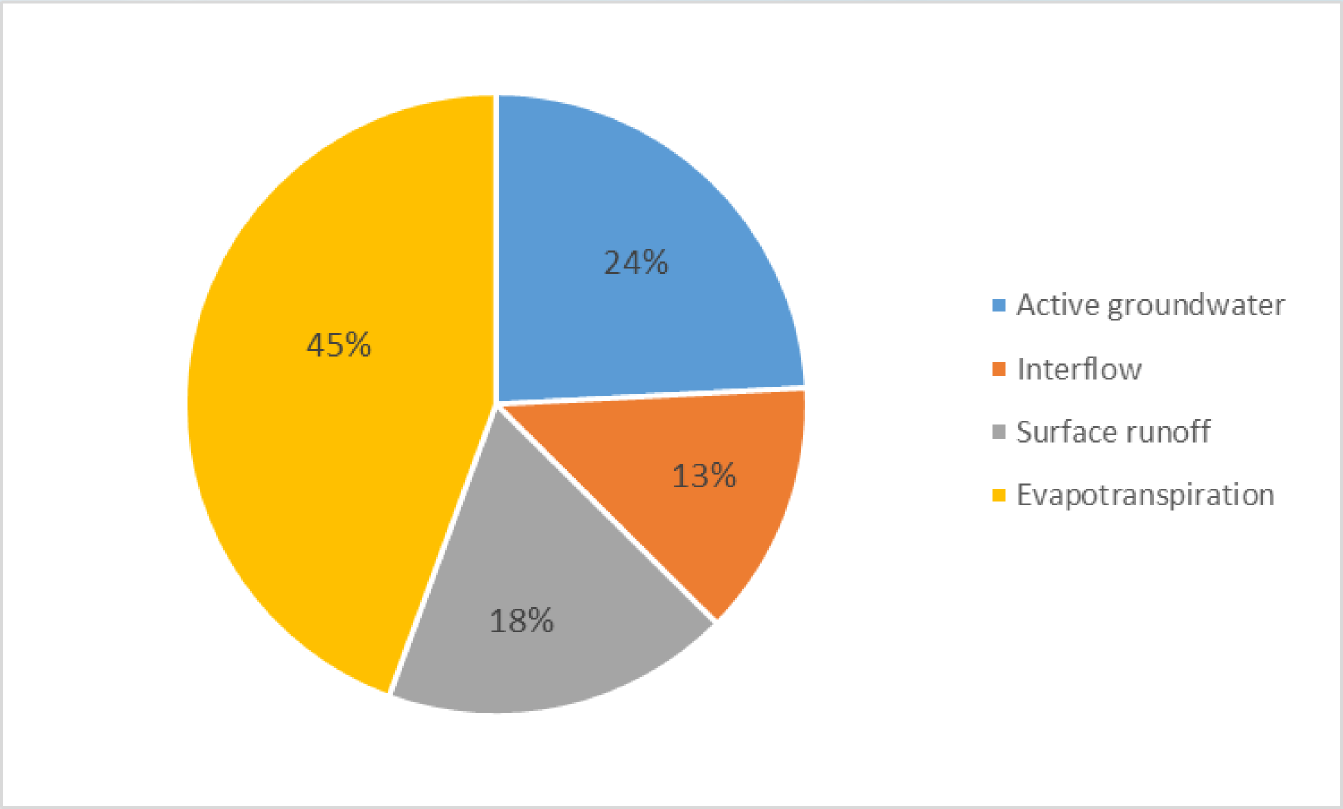
Water Balance – Green River Model

- Aligns with USGS (Woodward, 1995), Occurrence and Quality of Groundwater in Southwestern King County



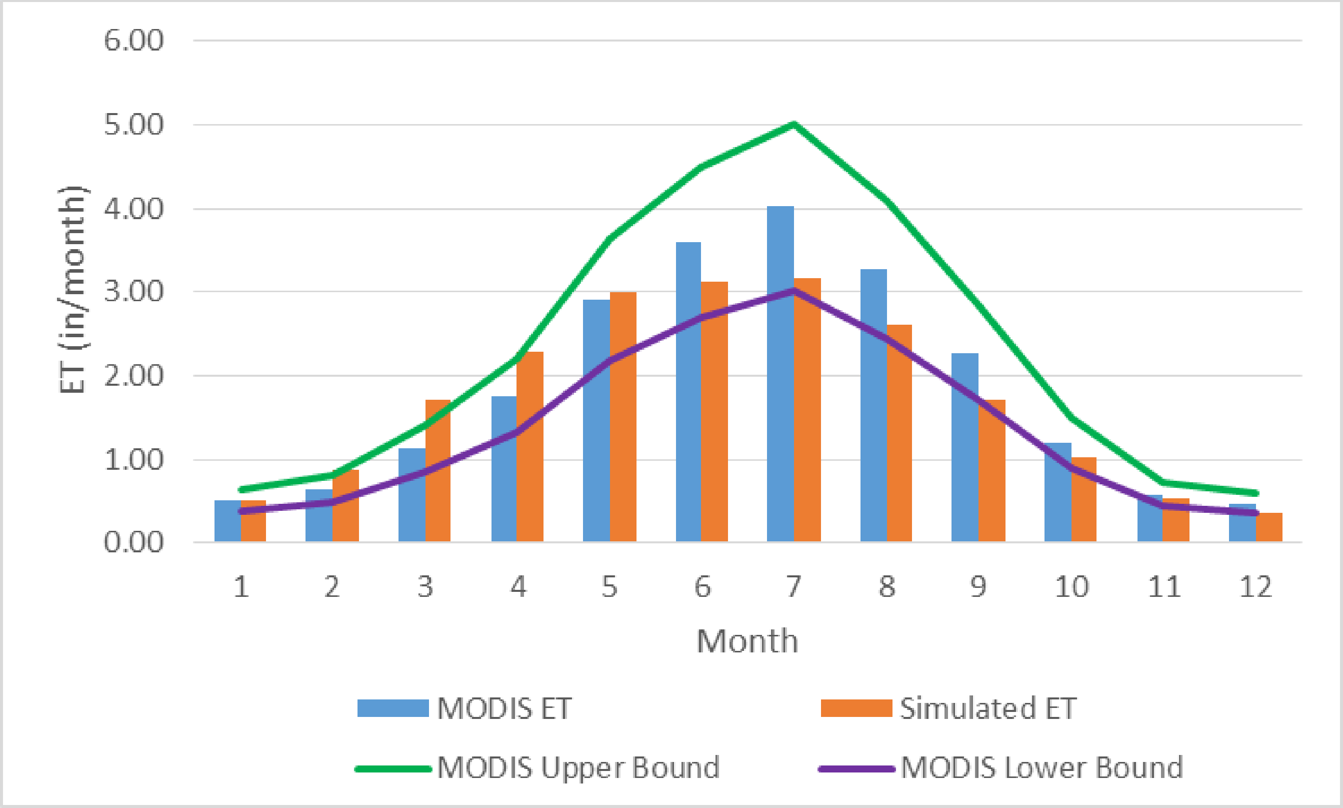
Water Balance – Duwamish Model

- Less Infiltration / more runoff (high imperviousness)



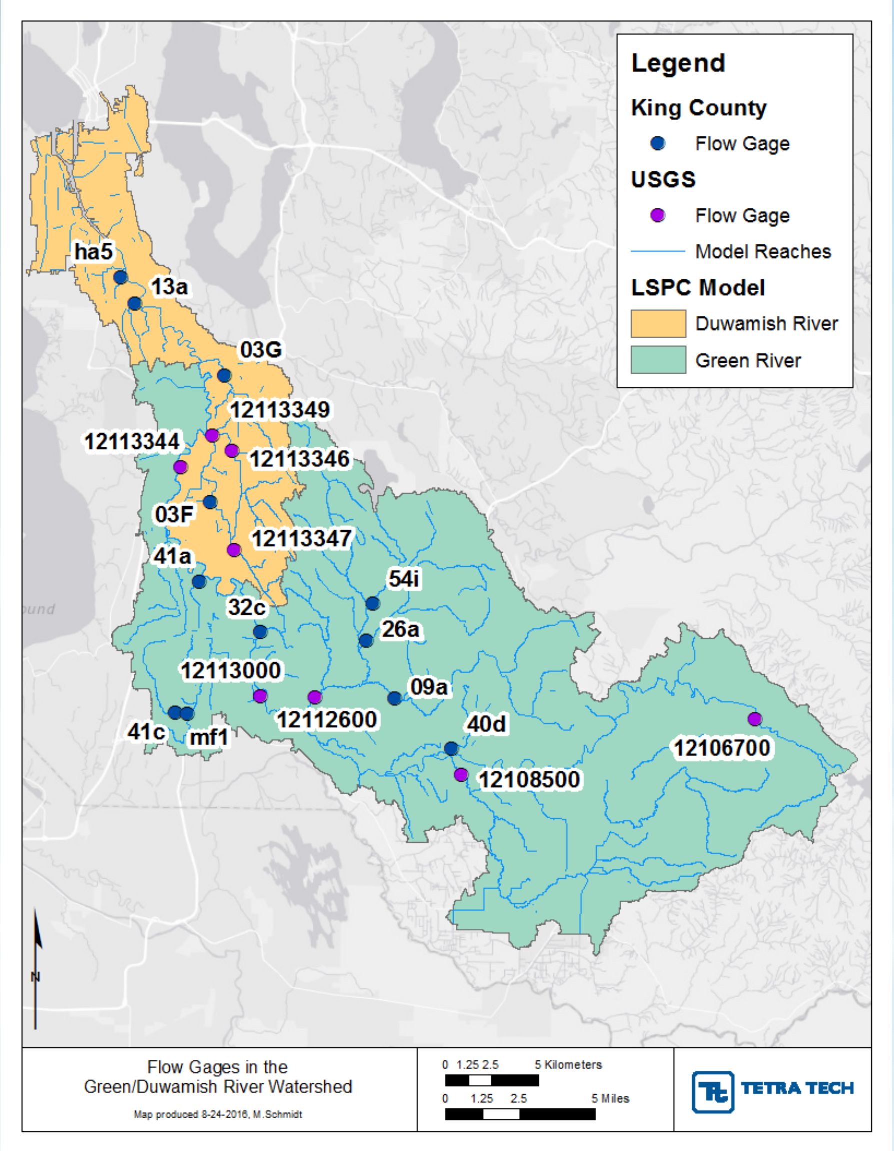
Evapotranspiration

► Consistent with MODIS satellite-based estimates

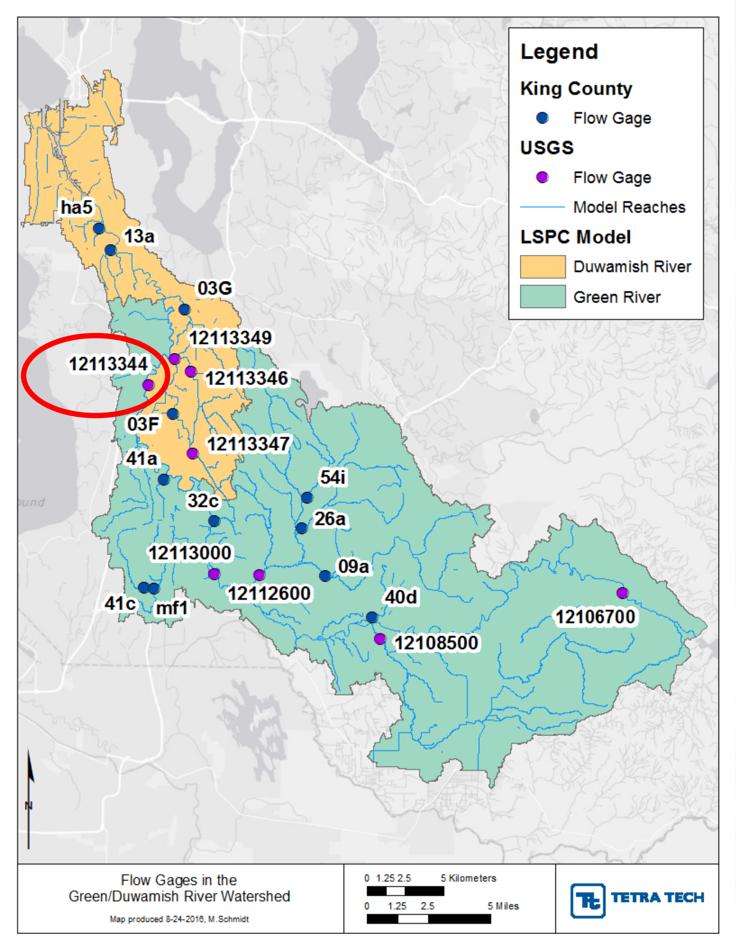


Flow Gaging

- 20 gages (8 USGS, 12 King Co.)
  - Within 1997-2015 model time frame
  - Periods of record vary
  - Quality of some records questionable (backwaters, shifting channels)

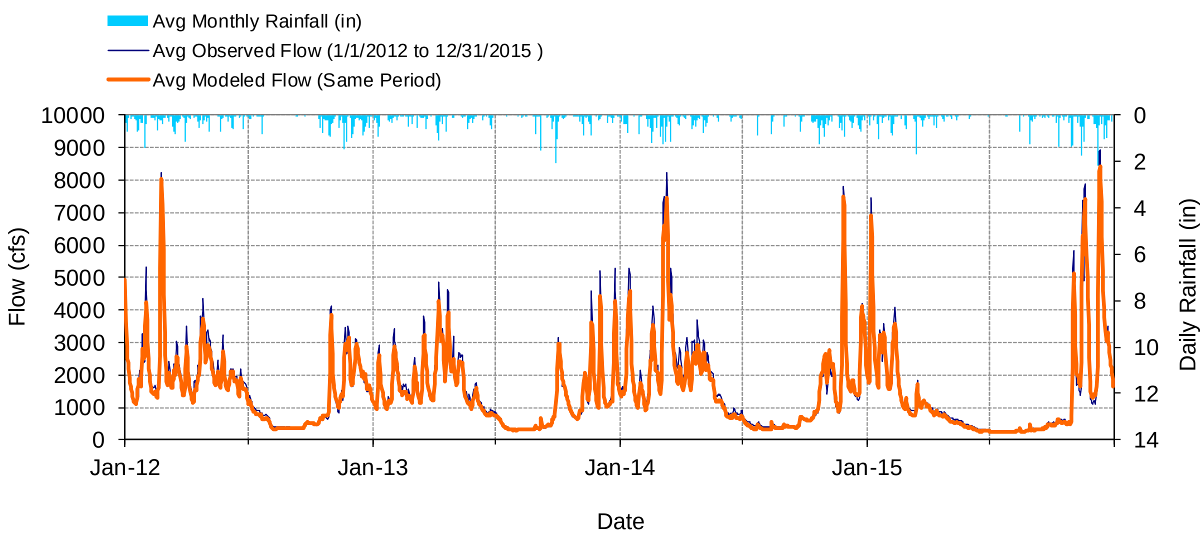


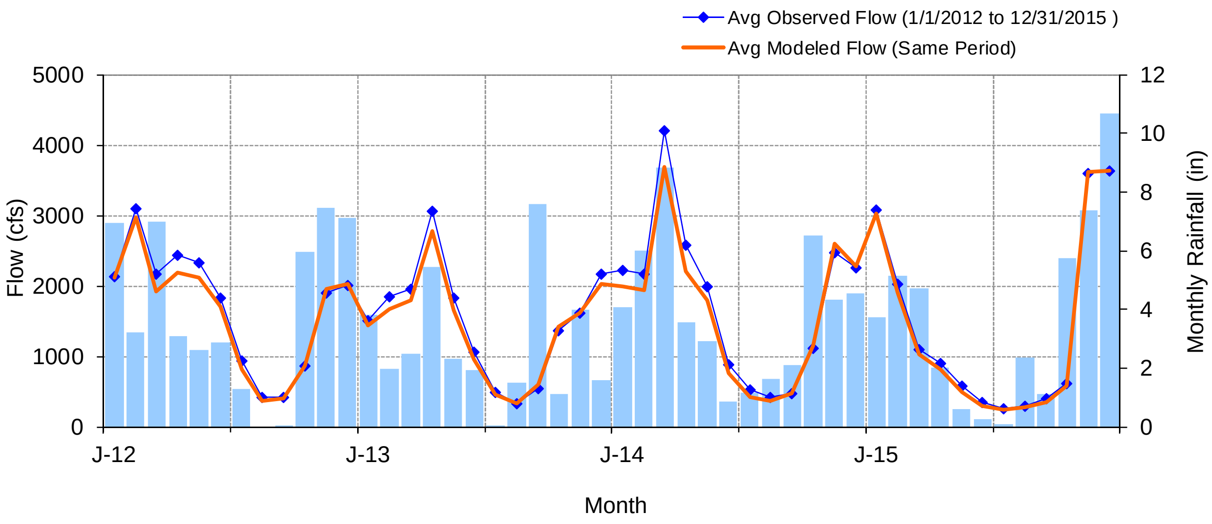
Example Flow Calibration: Green River at 200th St., Kent, WA



- ► USGS 12113344
- ► Established 2012
- ► Most downstream gage on mainstem
- ► May be affected by tidal backwater at highest flows

Green River at Kent, Matching Daily and Monthly Flows





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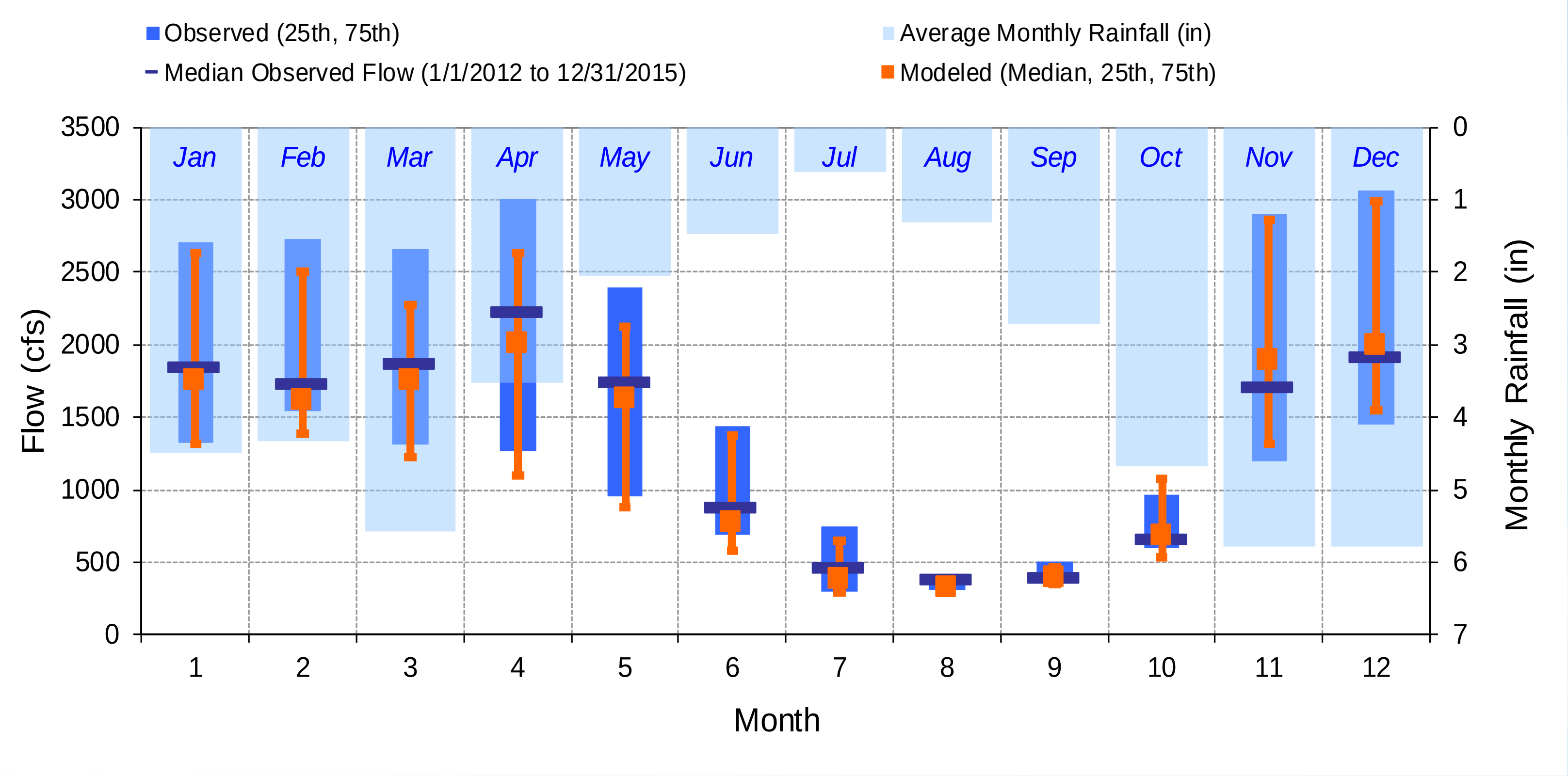
Monthly Flow Patterns



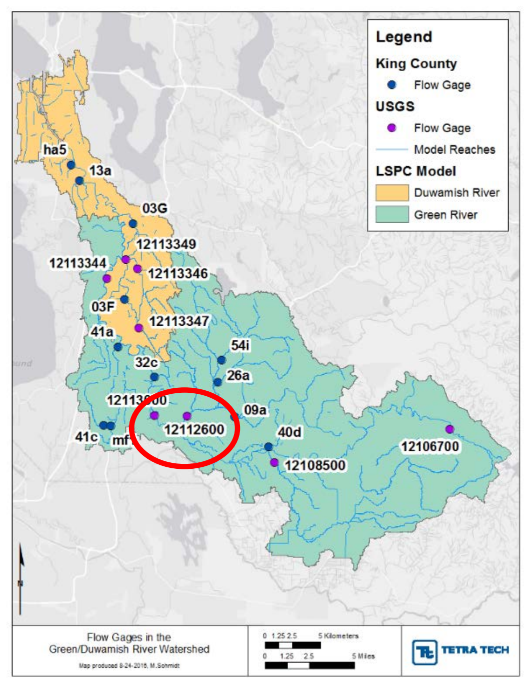
Detailed Statistical Analysis

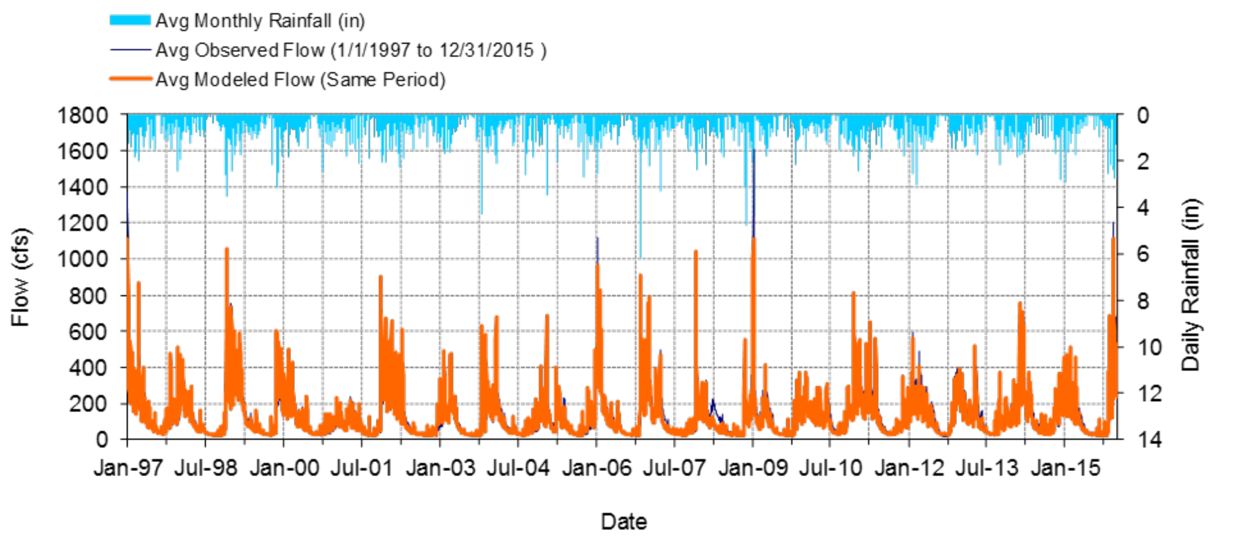
Observed Flow Gage

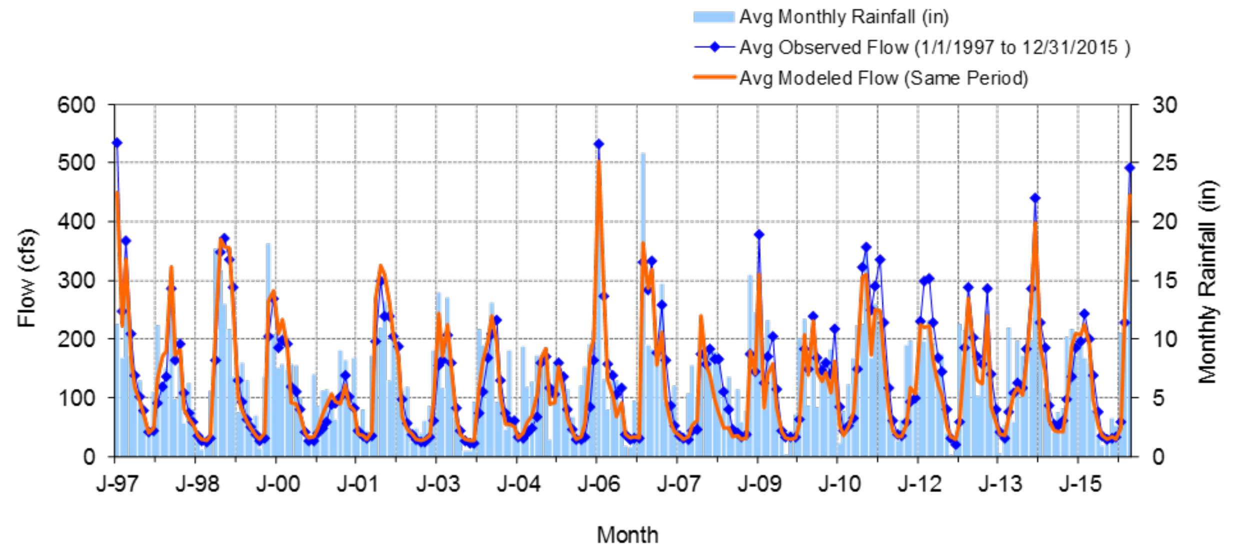
Green River at 200th St at Kent, WA (USGS 12113344)

Errors (Simulated-Observed)	*Error Statistics*
Error in total volume:	-5.75%
Error in 50% lowest flows:	-6.16%
Error in 10% highest flows:	-7.15%
Seasonal volume error - Summer:	-7.76%
Seasonal volume error - Fall:	0.37%
Seasonal volume error - Winter:	-7.31%
Seasonal volume error - Spring:	-10.41%
Error in storm volumes:	-9.90%
Error in summer storm volumes:	-1.78%
Nash-Sutcliffe Coefficient of Efficiency, E:	0.973
Baseline adjusted coefficient (Garrick), E':	0.854
Monthly NSE	0.979
Obs Baseflow	74.3%
Sim Baseflow	75.4%
Baseflow fraction error	1.1%
Coefficient of determination, r^2	0.98
Weighted r^2	0.92

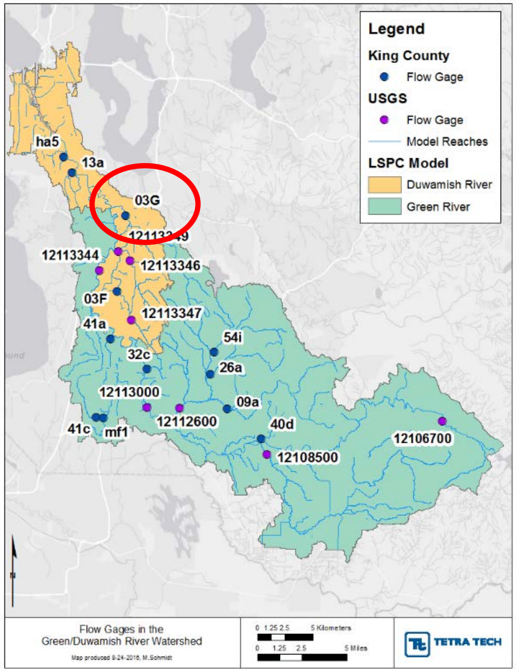
Big Soos Creek near Auburn (12112600)

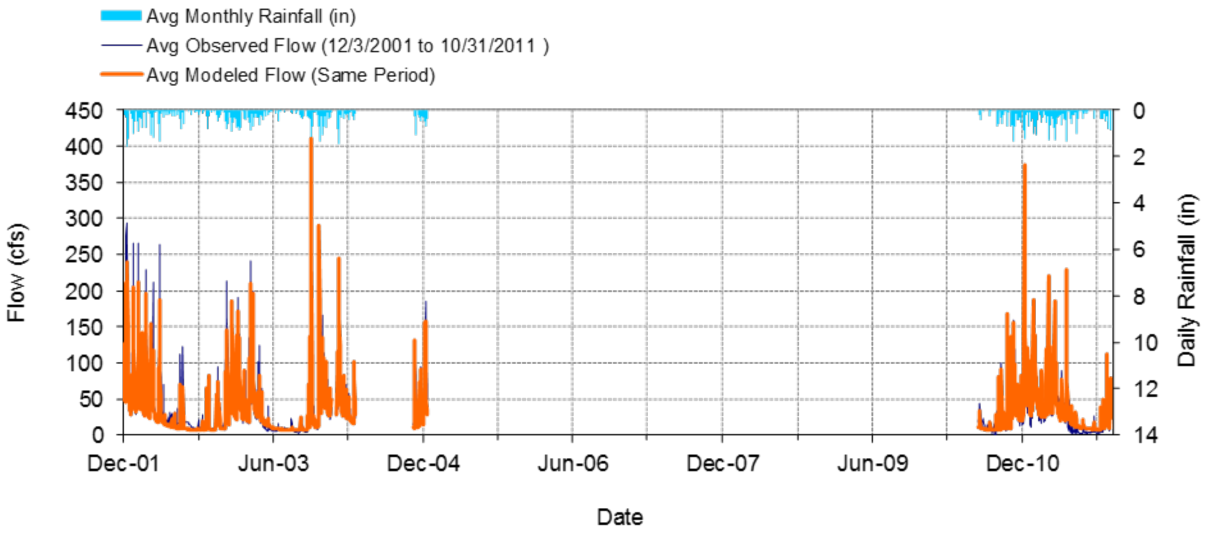


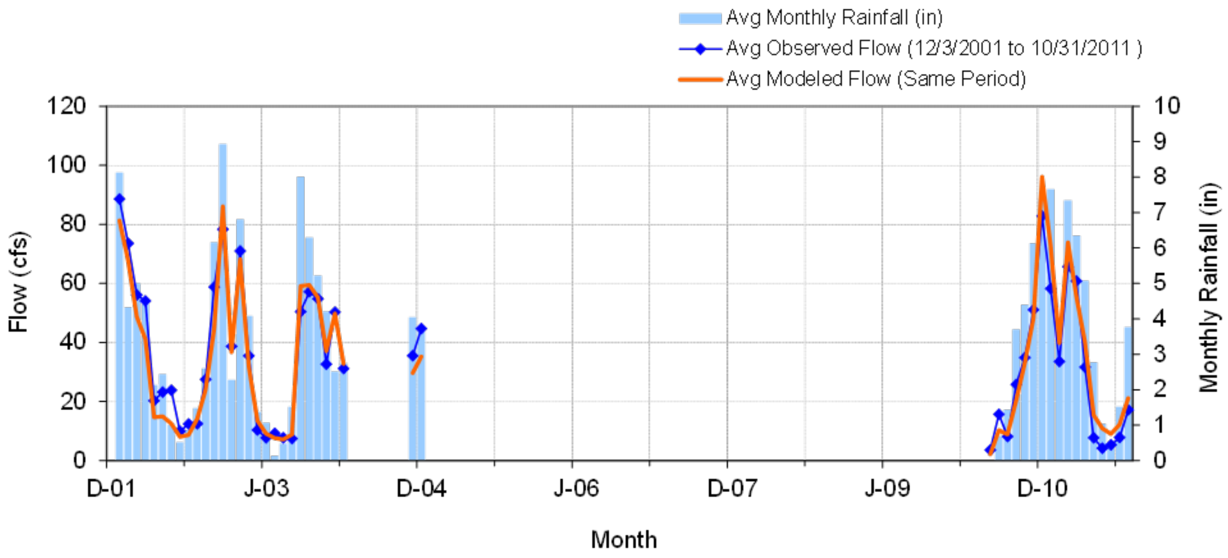




Springbrook Creek at O'Grady Way (03G)







QAPP does not establish hard targets for flow calibration, because:

- 1. Overall model quality cannot be fully captured in numeric error statistics.
- 2. Error can vary widely depending on the system; irreducible error cannot be predicted at the outset of the project.
- 3. It may not be possible to reduce error below numeric acceptance criteria without additional data collection.
- 4. Model acceptance is a policy decision of regulatory agency management and should involve consideration of numerous factors and goals in model quality.

But, literature does suggest qualitative ranges

Model Component	Very Good	Good	Fair	Poor
1. Error in total volume	≤ 5%	5 - 10%	10 - 15%	> 15%
2. Error in 50% lowest flow volumes	≤ 10%	10 - 15%	15 - 25%	> 25%
3. Error in 10% highest flow volumes	≤ 10%	10 - 15%	15 - 25%	> 25%
4. Error in storm volume	≤ 10%	10 - 15%	15 - 25%	> 25%
5. Winter volume error (JFM)	≤ 15%	15 - 30%	30 - 50%	> 50%
6. Spring volume error (AMJ)	≤ 15%	15 - 30%	30 - 50%	> 50%
7. Summer volume error (JAS)	≤ 15%	15 - 30%	30 - 50%	> 50%
8. Fall volume error (OND)	≤ 15%	15 - 30%	30 - 50%	> 50%
9. NSE on daily values	> 0.80	> 0.70	> 0.60	≤ 0.60
10. NSE on monthly values	> 0.85	> 0.75	> 0.65	≤ 0.65

Simul-taneous Fit to All Gages (Green River Model)

Flow Gage Name (Gage Number)	Section	Gage Area as Percent of Total Watershed	Percent Error in Total Volume	Percent Error in 50% Lowest Flow Volumes	Percent Error in 10% Highest Flow Volumes	Daily NSE	Monthly NSE
Green River at Purification Plant near Palmer, WA (USGS 12106700)	Upper Green	3.45%	2.42%	6.07%	0.22%	0.983	0.993
Crisp Creek at Green River Rd (KC 40d)		1.38%	19.1%	-3.71%	36.1%	0.060	-0.029
Newaukum Creek nr Black Diamond (USGS 12108500)		10.5%	-1.54%	12.0%	-14.5%	0.833	0.902
Big Soos Creek nr Auburn (USGS 12112600)	Soos Creek	25.6%	-5.77%	-9.40%	2.79%	0.870	0.910
Covington Creek nr Mouth (KC 09a)		8.33%	-5.27%	-3.62%	8.19%	0.683	0.835
Jenkins Creek nr Mouth (KC 26a)		6.45%	2.54%	-1.42%	6.55%	0.829	0.886
Little Soos Creek at SE 272 (KC 54i)		1.42%	-5.29%	6.97%	-10.9%	0.601	0.847
Green River nr Auburn (USGS 12113000)	Lower Green	67.9%	-5.47%	-3.74%	-8.53%	0.964	0.978
Green River at 200th St. at Kent, WA (USGS 12113344)		87.9%	-5.75%	-6.16%	-7.15%	0.973	0.979
Mill Creek at SR181 (KC 41a)		5.14%	-11.0%	6.75%	-3.29%	0.676	0.899
Mill Creek at Peasley Canyon (KC mf1)		2.28%	-4.94%	26.5%	-5.58%	0.763	0.883
Mill Creek nr Peasley Canyon Rd (KC 41c)		1.61%	-3.66%	-3.12%	-7.20%	0.836	0.894
Olson Creek at Green River Rd (KC 32c)		0.71%	9.15%	93.9%	-8.49%	0.797	0.900

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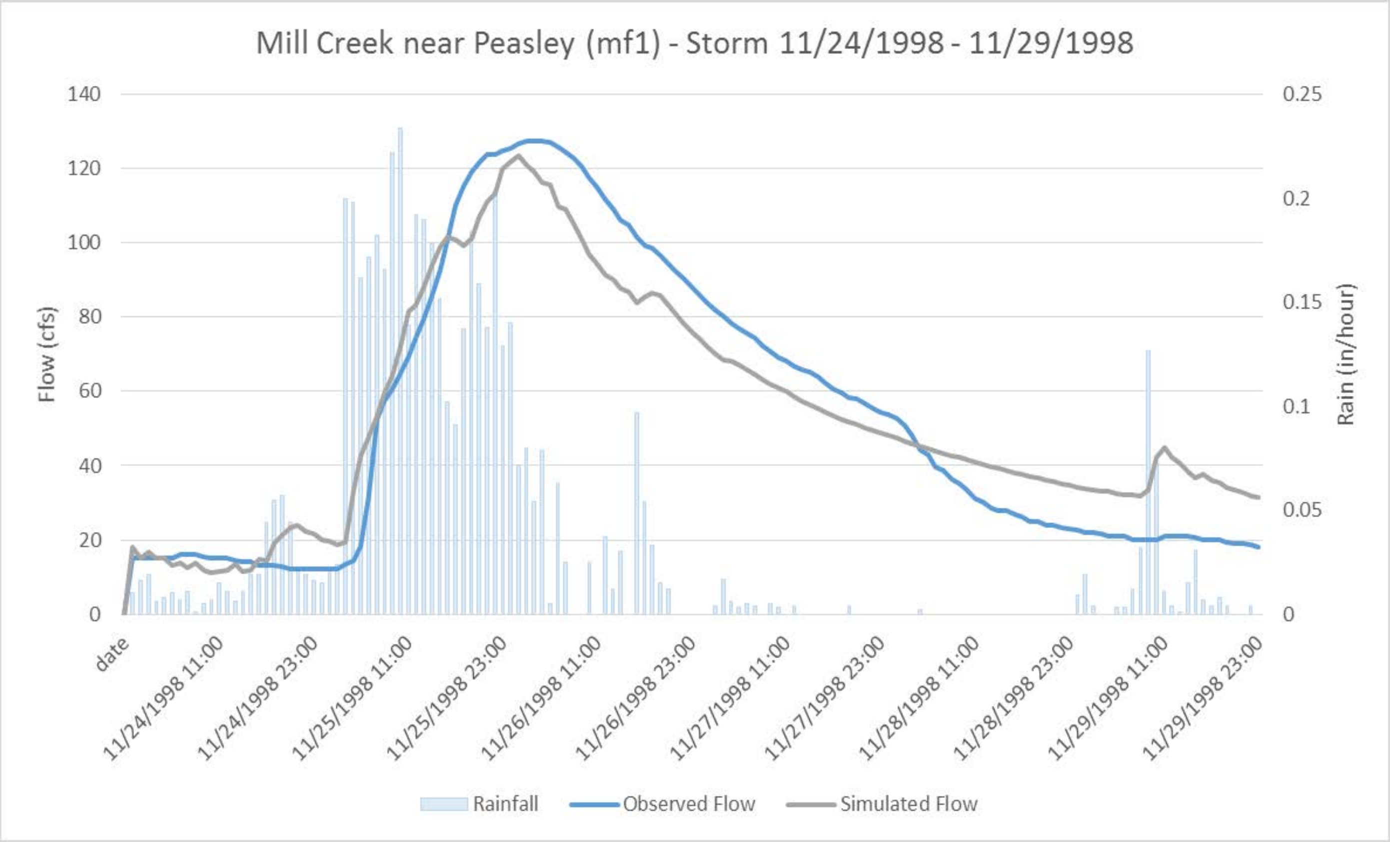
Simultaneous Fit to All Gages (Duwamish Model)

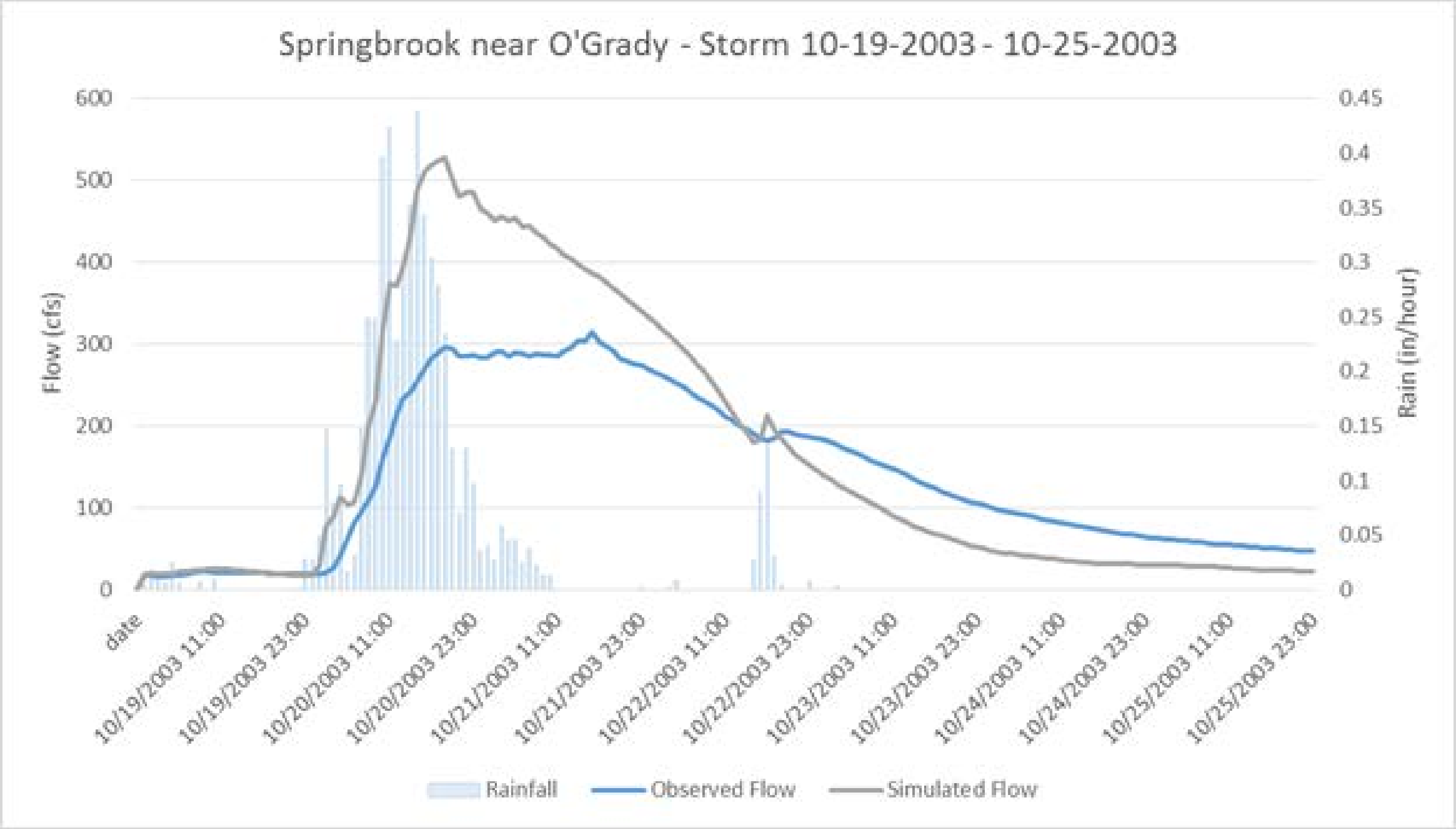
Flow Gage Name (Gage Number)	Section	Gage Area as Percent of Total Watershed	Percent Error in Total Volume	Percent Error in 50% Lowest Flow Volumes	Percent Error in 10% Highest Flow Volumes	Daily NSE	Monthly NSE
Mill Creek (Kent) above Diversion (Black R.) (KC 03F)	Black River	1.85%	-5.05%	5.75%	-11.3%	0.860	0.965
Mill Creek at Earthworks Park at Kent, WA (Black R.) (USGS 12113347)		0.96%	2.1%	5.06%	-8.11%	0.766	0.874
Mill Creek near mouth at Orillia (Black R.) (USGS 12113349)		2.16%	-8.93%	-8.23%	-3.93%	0.881	0.930
Springbrook Creek at O'Grady Way (Black R.) (KC 03G)		9.83%	-1.97%	-2.61%	-0.79%	0.863	0.933
Springbrook Creek at Orillia, WA (Black R.) (USGS 12113346)		3.24%	-2.00%	-8.62%	-4.59%	0.722	0.733
Duwamish River Tributary 0003 (KC 13a)	Duwamish	0.21%	16.1%	-7.08%	-6.30%	0.841	0.923
Hamm Creek South Fork (KC ha5)		0.28%	-8.33%	-12.7%	4.50%	0.627	0.639

Simulation of Hourly Flows

- Generally reasonable
- Might need additional attention in important source areas



Simulation of Hourly Flows



LSPC Model Uncertainty and Usability

Green-Duwamish PLA

LSPC Model Uncertainty and Usability

- USEPA, Council for Regulatory Environmental Modeling, defines a model as "*a simplification of reality that is constructed to gain insights into select attributes of a particular physical, biological, economic, or social system*"
- All models have uncertainty
- All models can be improved with further data and effort
- Is this model good enough for the PLA?
  - Current model for hydrology and hydraulics is credible
  - Fit for most gages is rated "good" or "very good"
  - Won't fully understand how well it fits PLA purposes until it is extended to simulate sediment and pollutant transport

Sources of Watershed Model Uncertainty

Five general categories of uncertainty in model structure and input data

1. Model Formulation
2. Model Forcing (external data time series)
3. Land Use Representation
4. Calibration Data
5. Hydraulics Representation

► *Note: These sources are in addition to any shortcomings in the model calibration effort itself*…

Key Uncertainty: Channel Hydraulics

- LSPC 1-D representation of channels works best with hydraulics from an external analysis
- Could create/calibrate additional local-scale HEC-RAS and SWMM models to better specify hydraulic response
  - Will have limited effect on hydrology calibration except for shape of flood hydrograph
  - Important for sediment scour and deposition simulation
  - Obtain and make use of existing local stormwater conveyance models?
- *Recommendation: At a minimum, track availability of such models and incorporate information into LSPC as it becomes available*

Key Uncertainty: Impervious Disconnection

- Quantitative basis for EIA was not available, remains a calibration lever
- Further investigation of representation in local detailed stormwater conveyance models may be useful
- Consider small watershed gaging to resolve EIA (as distinct from DCIA) from storm responses using methods of Ebrahimian et al.

Ebrahimian, A., B.N. Wilson and J.S. Guilliver. 2016a. Improved methods to estimate the effective impervious area in urban catchments using rainfall-runoff data. *Journal of Hydrology*, 536: 109-118.

Ebrahimian, A., J.S. Guilliver, and B.N. Wilson. 2016b. Effective impervious area for runoff in urban watersheds. *Hydrological Processes*, doi:10.1002/hyp.10839.

Summary

- LSPC model of entire study area successfully developed and calibrated for hydrology
- Model is ready to move forward with sequential calibration of sediment and toxics
- Hydrology/hydraulics can be further refined over time – should be done in conjunction with sediment model calibration process
- Finer resolution can be added where needed to address areas of high interest – either by adding resolution to unified model or splitting out key areas into separate, fine scale models

MODEL DEMONSTRATION

Movie showing model response to high precipitation input of January 2009

- Showing larger reaches only
- Aggregated from 1-hr to 6-hr scale to create manageable animation

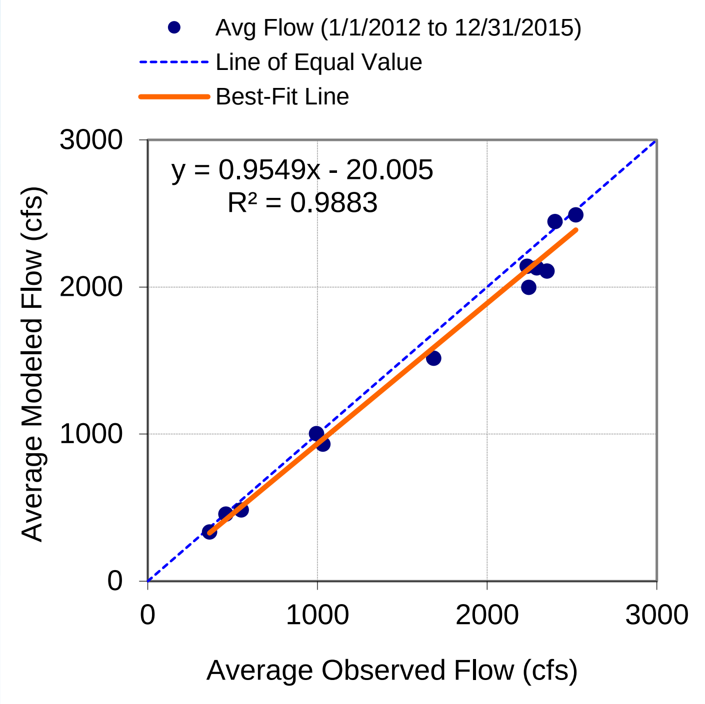
Questions and Discussion

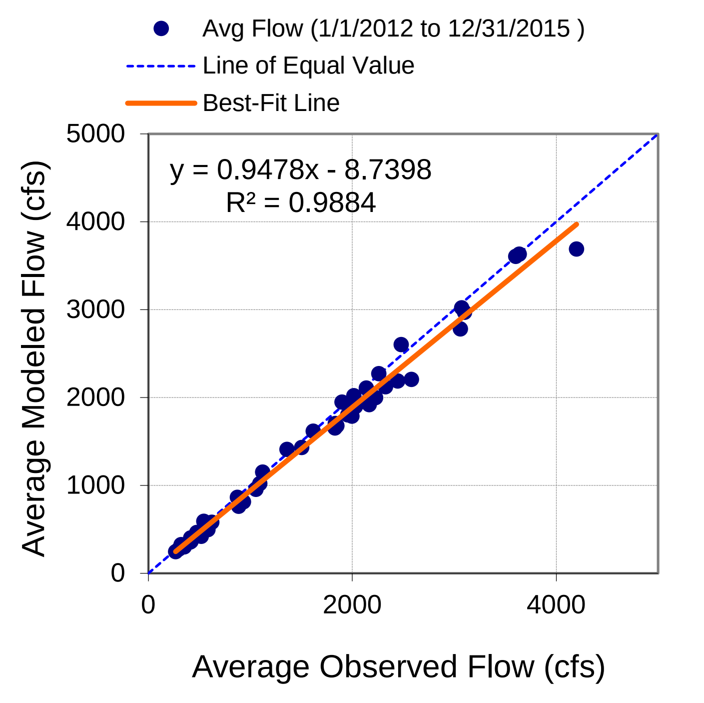
Extra Slides

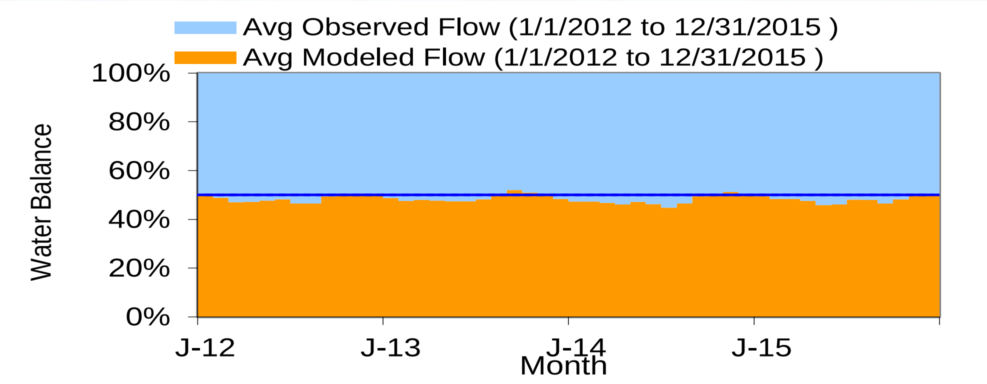
Summary of Data Requests at TAC Meeting #8

1. MS4s provide detailed stormwater conveyance models where available [*not provided*]
   - Tt use to improve hydraulic tables
   - Tt consult with MS4s on extent of additional reductions in EIA associated with BMP installations
2. King Co.: provide information gage rating curve calibration [*available information provided*]
3. Water utilities: requested additional information on well withdrawals that are included in the HSPF models [*available information provided*]

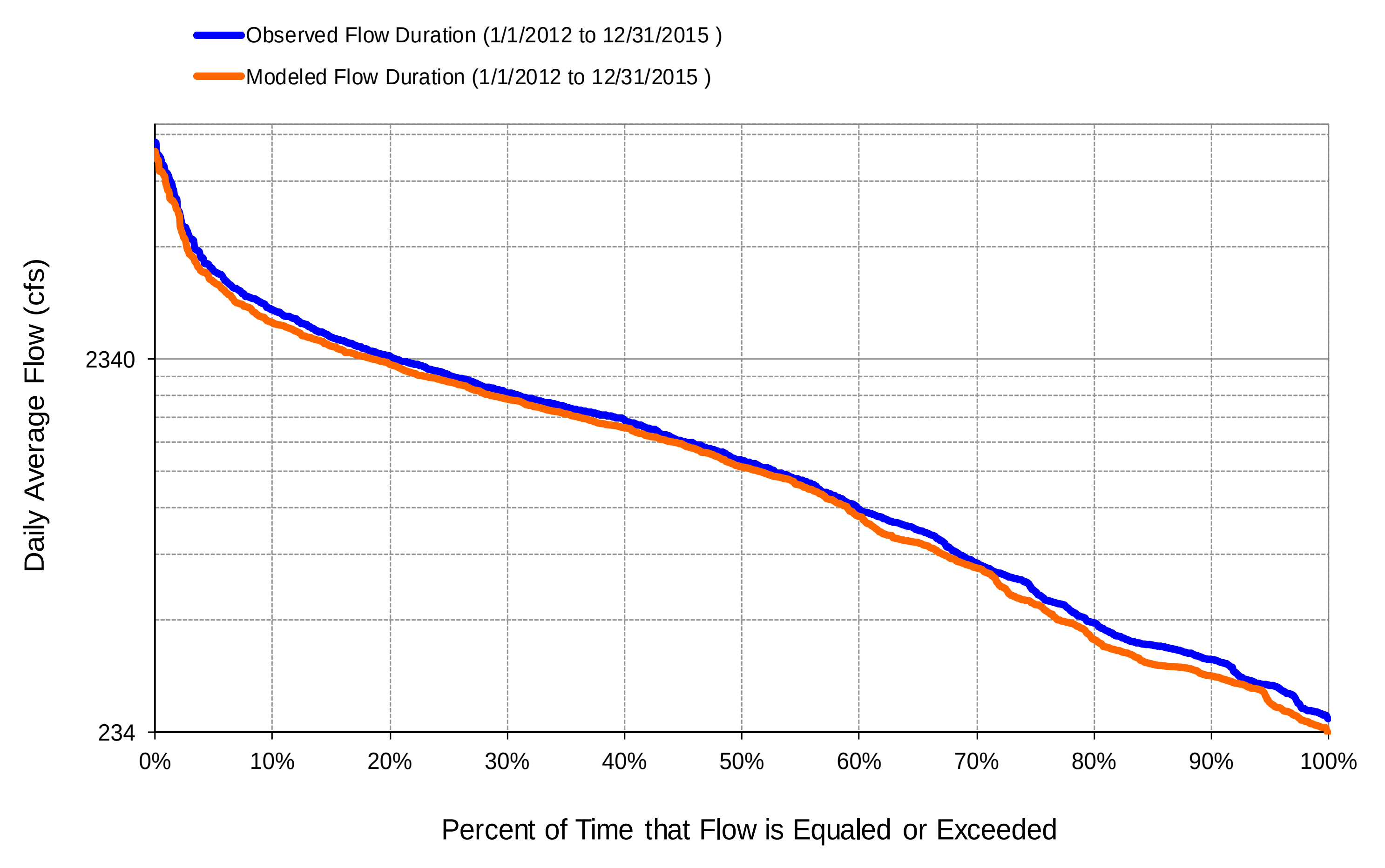
Annual and Monthly Flows – Green River at Kent







Flow Duration Plot – Green R at Kent (Exceedance Probability)



Uncertainty: 1. Model Formulation

LSPC/HSPF: Well established and tested model formulation, selected as appropriate to PLA in QAPP, but acknowledge the following:

a. Lumped model: assume properties of a given upland hydrologic response unit type are constant across subbasin

b. One-dimensional stream segments: Limits ability to simulate fine-scale sediment bed and bank scour and deposition processes

- *These limitations believed to be minor relative to PLA needs; can be addressed through finer-scale application if needed*

Uncertainty: 2. Model Forcing

Precipitation drives the model, based on PRISM interpolation. Expect this to be generally accurate, on average, but may bias response to individual events

a. Surface water diversions and effects of groundwater pumping on surface flows are not fully known
b. Groundwater transfers between subbasins not fully known

- *Creation of a groundwater model of the valley could resolve groundwater interactions – but may not be needed for PLA purposes.*
- *Could revisit PRISM interpolation routines and Doppler radar for local areas – if needed.*

Uncertainty: 3. Land Use Representation

a. Primarily based on NLCD 2006 plus LiDAR. Resolution limited to NLCD classes

b. Does not represent land use changes over time

- *More detailed analysis using other data sources might be appropriate for areas with significant potential sources of toxics loads.*
- *Land use change not a major issue at the watershed scale, but might be important to results in some local areas. (LSPC can represent land use change over time if needed.)*

Uncertainty: 4. Calibration Data

Gaged flows are estimates based on converting stage to flow using a rating curve

a. Rating curves affected by changes in channel form, necessity of extrapolation to very high or low flows

b. Some gages affected by backwater effects, making high flow observations suspect

c. Many areas not gaged, others gaged for only short periods

- *Can't fix defects in past gaging. Can maintain robust gaging and monitoring program and refine gaps in model calibration in future.*

Uncertainty: 5. Hydraulics

Channel configuration and hydraulics determine shear stress exerted on bank/bed and thus ability to mobilize and move sediment and associated pollutants

a. LSPC 1-D representation of reaches works best with hydraulics from external analysis (e.g., HEC-RAS, SWMM)

b. Specification of Effective Impervious Area (EIA) adjusted in calibration

- *Model performance could be improved with additional hydraulic models; need to incorporate local SWMM models?*
- *EIA calibration is a potential issue for further investigation (see below)*