2012

Bottom-up Approaches to Optimize Urban Water Supply, Wastewater, Stormwater, Reuse, and Watershed Network Systems

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Presented at:

50 Years of Watershed Modeling

Engineering Conferences International

NCAR in Boulder, Colorado

September 2012

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Collaborators

- University of Colorado (1991-2003)
  - Donald Alexander, Lynn Buhlig, Beorn Courtney, Bill DeOreo, Bob Harberg, Jeff Harpring, Wayne Huber, Joong Lee, Istvan Lippai, Peter Mayer, Chelisa Pack, Marcus Quigley, Derek Rapp, David Sample, Laurel Stadjuhar, Eric Strecker, and Leonard Wright
- University of Florida (2003-2012)
  - Camilo Cornejos, Ken Friedman, Ruben Kertesz, Scott Knight, Jackie Martin, Rebecca McLarty, Miguel Morales, John Palenchar, Dan Reisinger, Matthew Rembold, Kristen Riley, Randy Switt, Leighton Walker, and Lukasz Ziemba

Research Sponsors

- Water Research Foundation
- U.S. EPA
- National Cooperative Highway Research Program
- Water Environment Research Foundation
- U.S. Army Corps of Engineers
- Florida Dept. of Environmental Protection
- South FL, Southwest FL, and St. Johns River Water Management Districts in Florida
- U.S. Geological Survey

Outline

- Why watersheds in urban areas?
- Build your own watershed starting with individual land parcels to evaluate centralized vs. decentralized water management options
- Agent-based modeling methods

Outline

- **Why watersheds in urban areas?**
  - **NRC study (Graf et al. 1999)**
  - **Boulder Creek Watershed (Heaney et al. 2000)**
- Build your own watershed starting with individual land parcels to evaluate decentralized vs. centralized water options
- Agent-based modeling methods

Sustainable Urban Water Infrastructure Systems

- Watershed Management
  - Hydropower
  - Water rights
  - Land use and energy planning
  - In-stream flow needs
  - Etc.
- Water Supply
  - Nature of urban water use
  - Impact of conservation in Florida
  - Dual water systems for reuse and fire protection
- Waste Water
  - CSO and SSO control
  - Reuse
- Storm Water
  - Characterization
  - Evaluation of LID & Other BMPs
  - Reuse
- System Integration

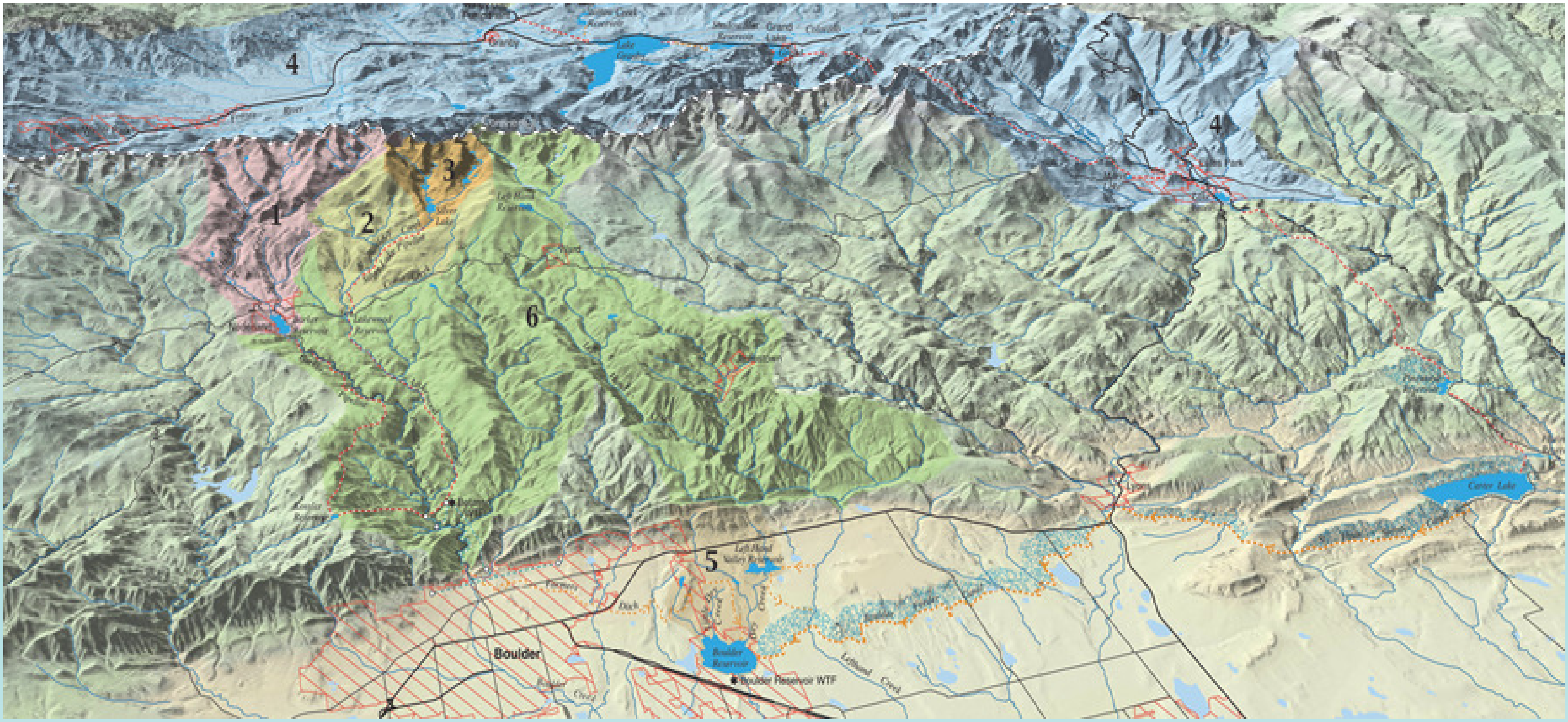
New Strategies for America's Watersheds
Graf et al. 1999 NRC Report

http://www.nap.edu/openbook.php?record_id=6020&page=R2

- Federal water agencies are defined by their missions and can't take an holistic view of watershed scale problems because of their project by project and mission focus
- Funding for watershed management is a major problem because most agency funding is for single purpose activities within a political jurisdiction
- Watershed approaches are easiest to implement at the local level

Boulder Creek Watershed is a Complex Maize of Natural and Human Systems

http://www.bouldercolorado.gov/files/Utilities/resources/Boulder%20Watersheds%20Map.pdf



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Boulder Water System Modeling
Five "Watersheds" to Consider

- Boulder Creek Watershed with Supply Canals
- Looped Water Supply Network
- Mostly Dendritic Wastewater Network
- Mostly Dendritic Stormwater Network
- Looped/Dendritic Reuse Network

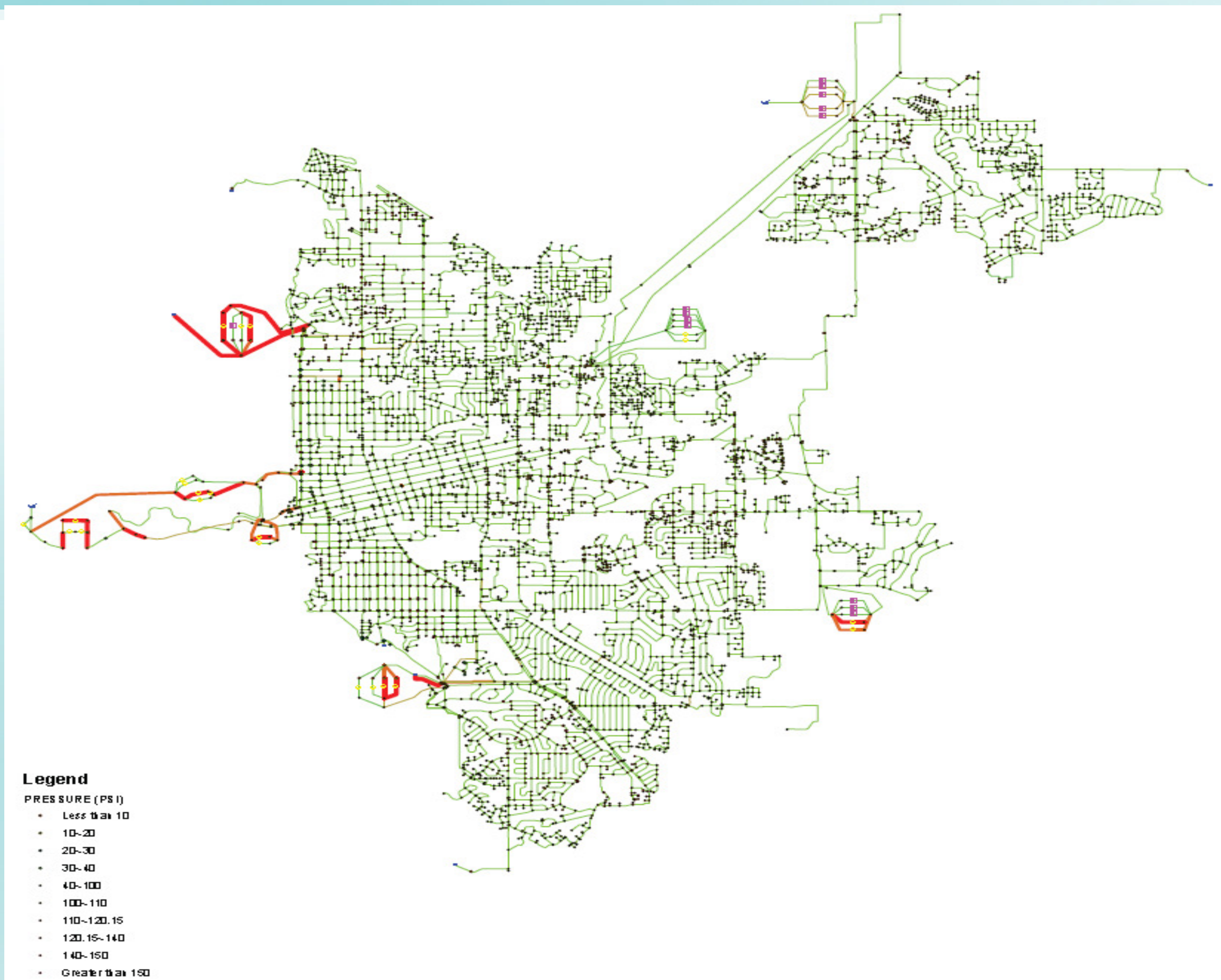
Boulder Creek Watershed Model Simulates/Optimizes Water Rights for the City of Boulder

http://www.bouldercolorado.gov/files/Utilities/WUMP/October_2011/Volume_4_-_October_2011.pdf

- Streamflows, water rights, diversions, exchanges, reservoir releases, return flows, etc.
- Facilities: reservoirs, pipelines, ditches, WTPs, and WWTPs
- Boulder's water supply system operations, including drought response triggers and demand reduction goals
- **Proprietary** model developed for a single stakeholder's use

Boulder Water Supply Hydraulic All Pipe Network

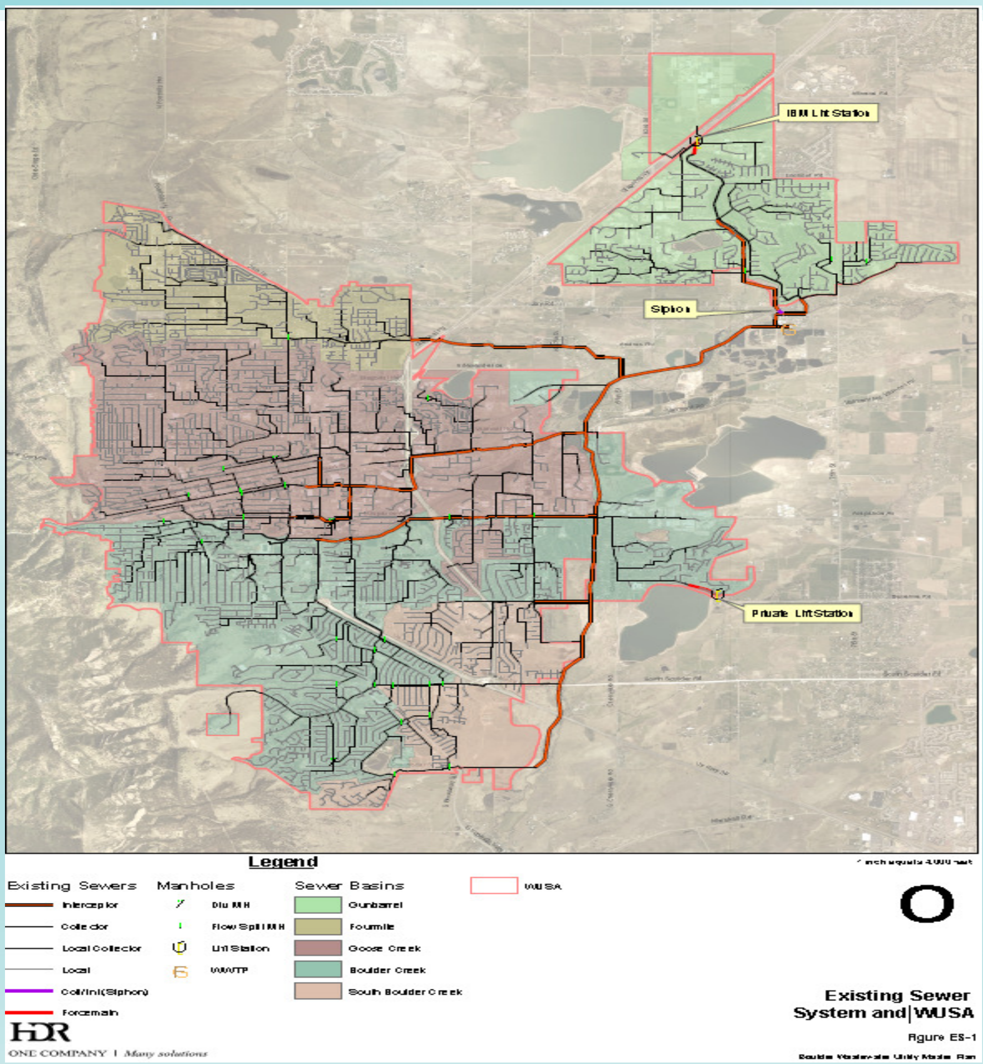
http://www.bouldercolorado.gov/files/Utilities/WUMP/October_2011/Volume_5_-_October_2011.pdf



- All pipe network
- Demands from customer billing data- about 40,000 accounts
- Irrigated area estimated for each parcel for water budget
- Advanced modeling capability

Boulder's 485 Sanitary Sewersheds

http://www.bouldercolorado.gov/files/Utilities/wastewater/Boulder%20WWCSMP%20Volume%201%20-%201st%20Draft%20101008.pdf



- 485 sewersheds range in size from 5 to 400 acres with an average of 33.6 acres
- About the same spatial scale as a TAZ
- Numerous interconnections
- All pipe modeling network
- Estimate wastewater supply from water billing records

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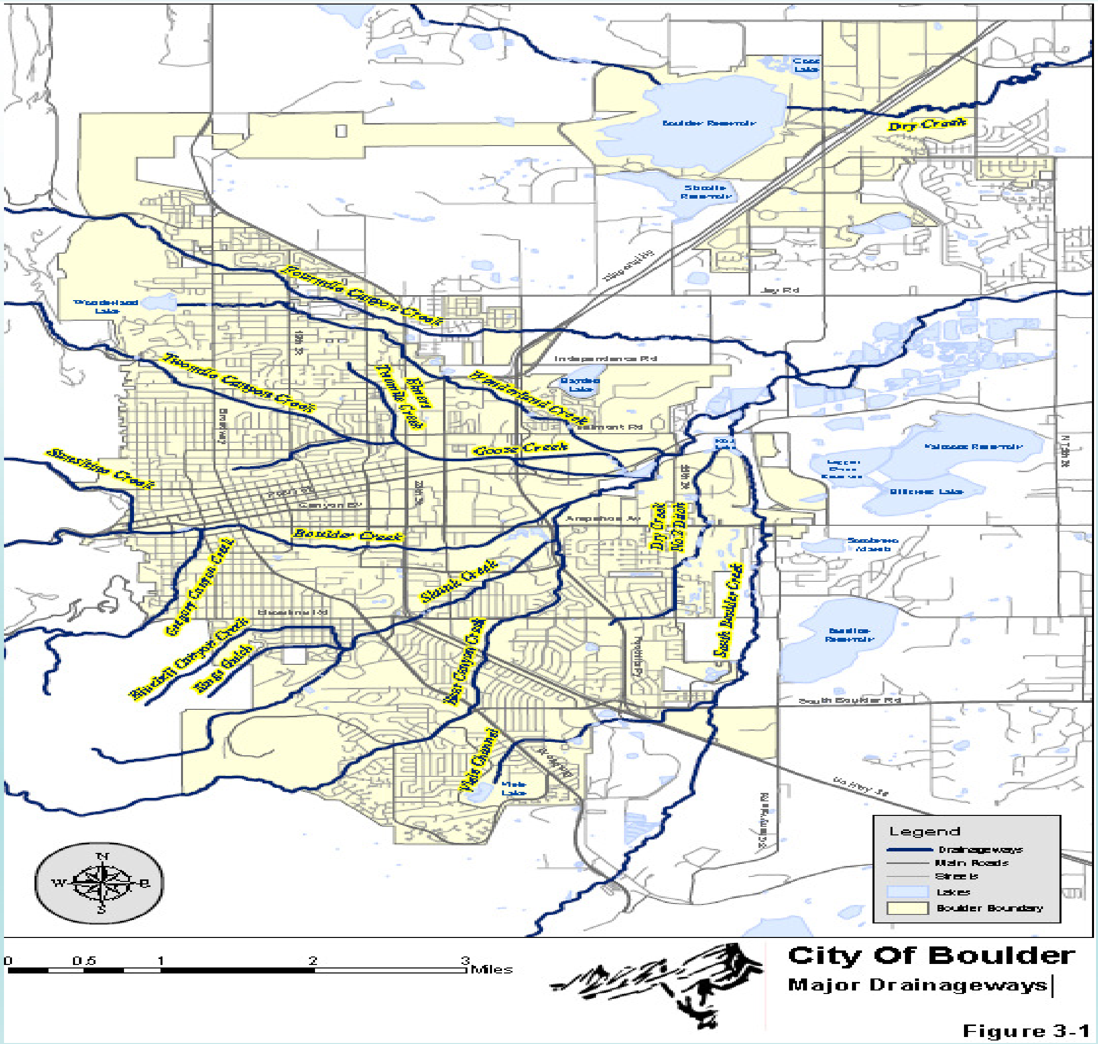
15 Major Drainageways



- Water delivery canals also serve as unplanned drainageways
- Sophisticated floodplain mapping models
- Minimum flow maintenance is important
- Stormwater quality modeling is not a priority activity

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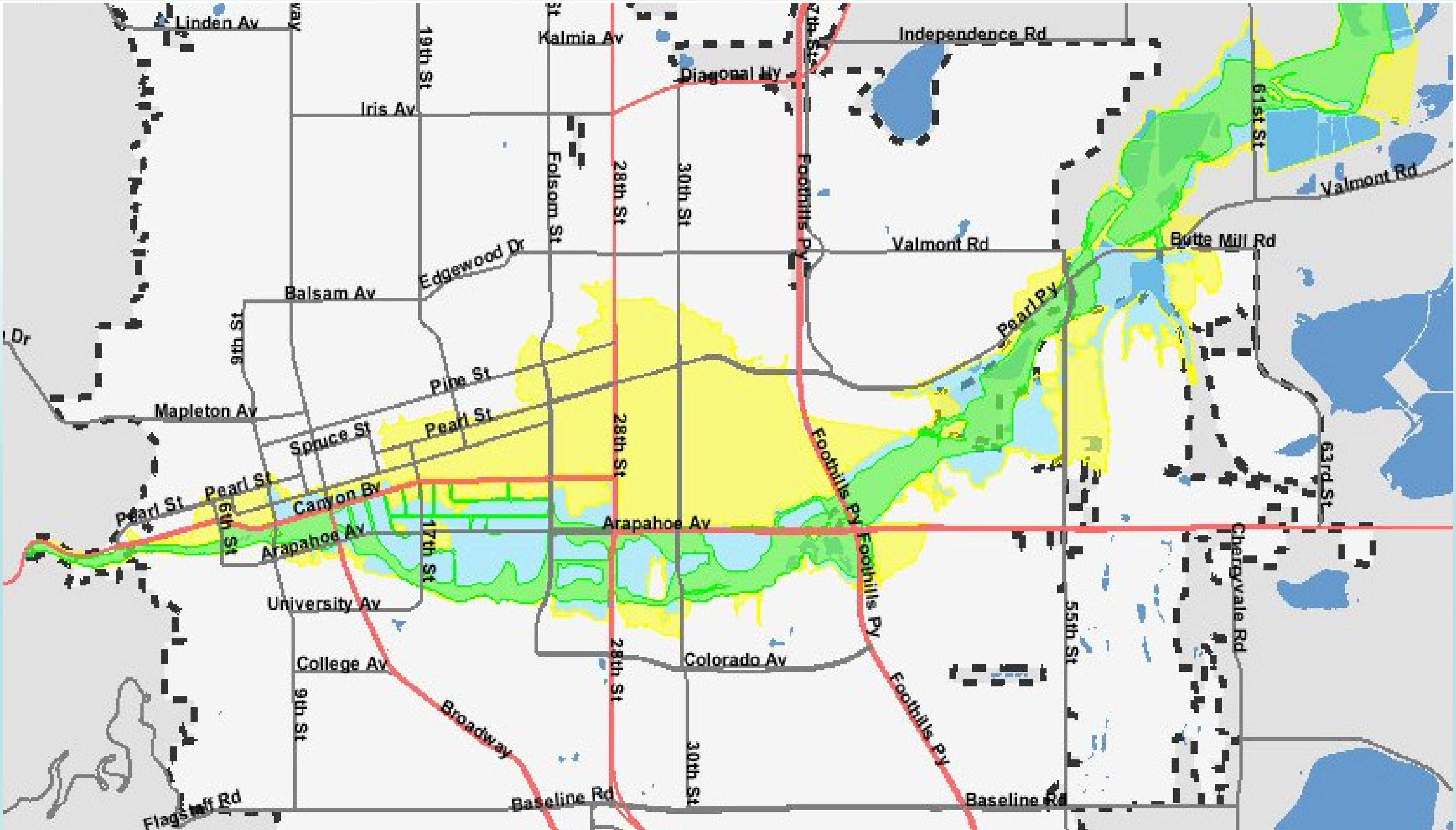
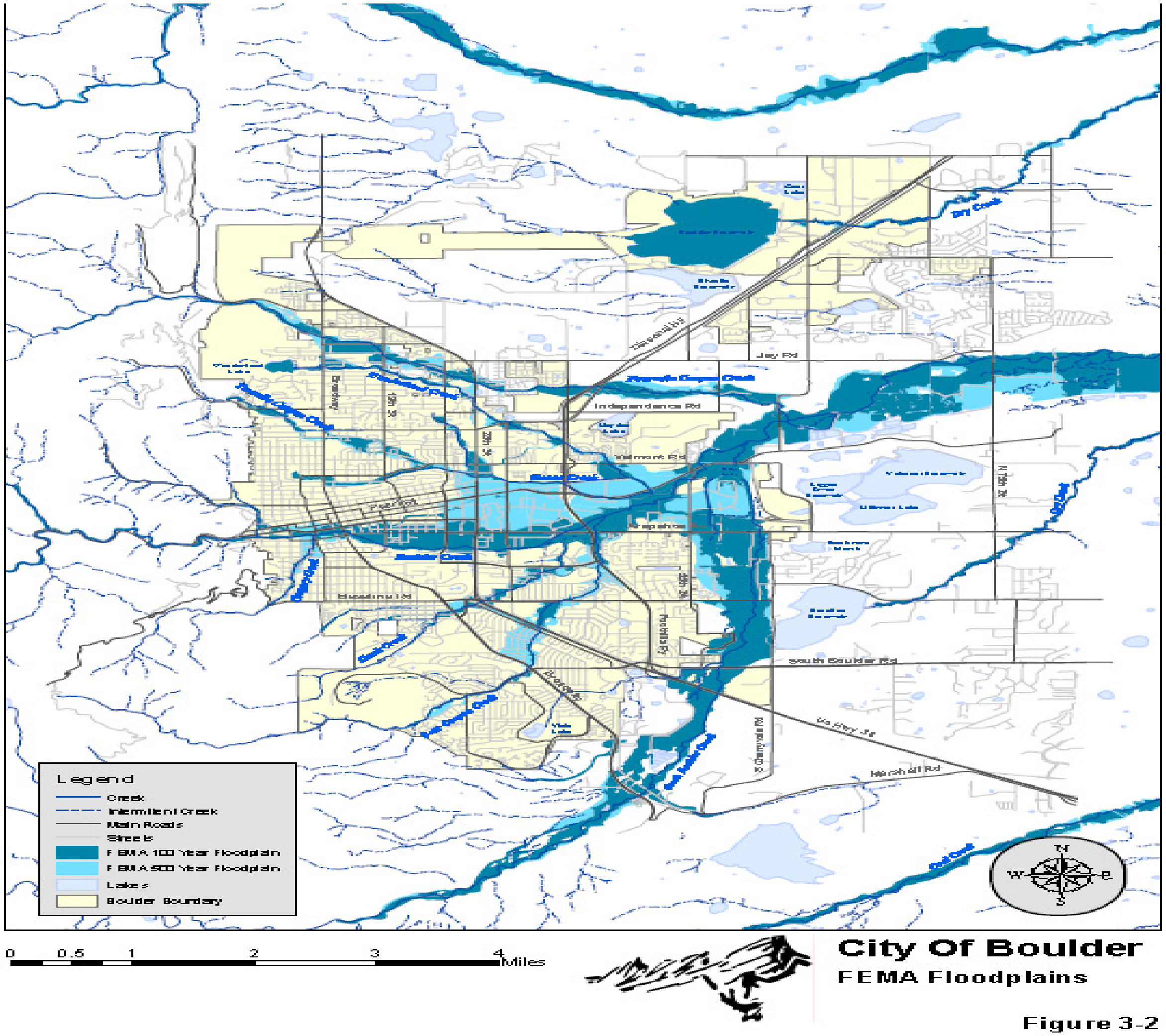
BCW High Flood Hazard Areas (Green-conveyance channel) and Yellow (proposed 100-500 year flood zone)

http://gisweb.ci.boulder.co.us/website/pds/pds_floodbase/viewer.htm



Land in 100 & 500 year floodplains



- 15% of the community is in the floodplain
- Flash flood hazards-Thousands of people and about 3,600 structures with an assessed valuation of almost $1 billion are within the 100 year floodplain

Dedication of Presentation

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Why Watersheds?
Conclusions

- Current Boulder Creek Watershed is dominated by man's influences
- Need to work across multiple combinations of the remaining natural system and man-made water supply, wastewater, stormwater, hydropower, and other water resource systems
- Historical operating policies are vital to obtain a process level understanding

Outline

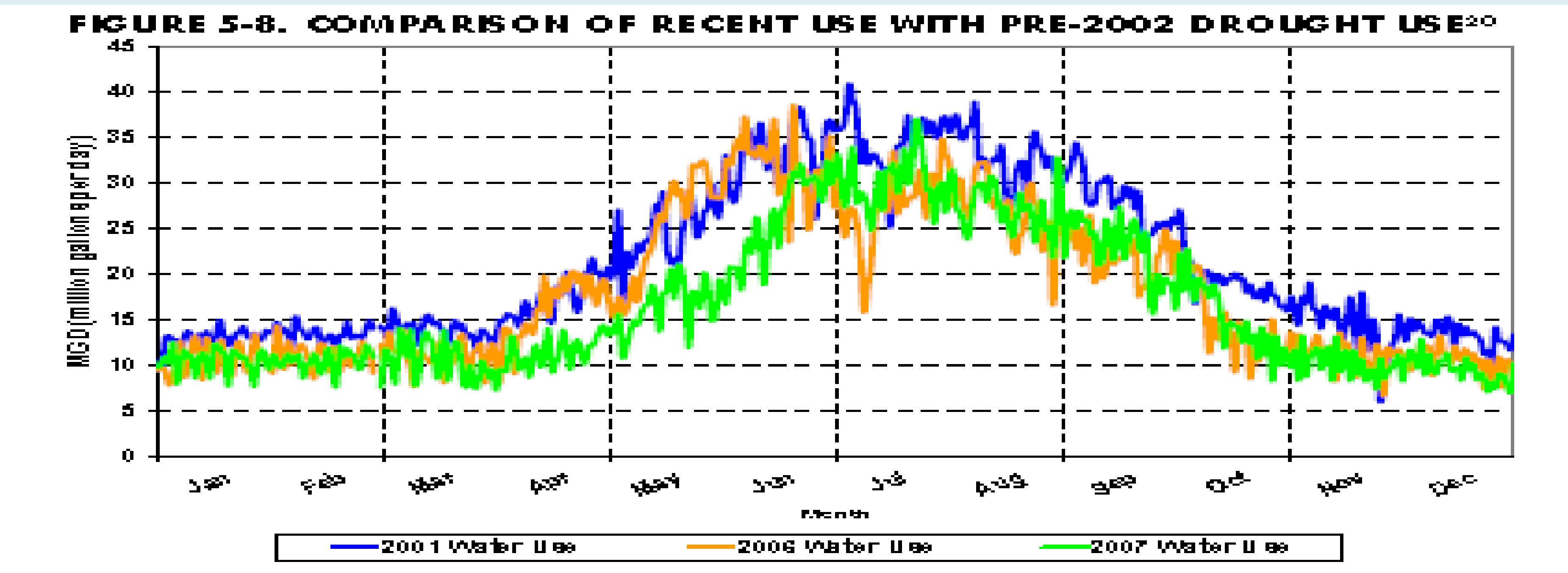
- Why watersheds in urban areas?
- **Build your own watershed starting with individual land parcels to evaluate centralized vs. decentralized water management options**
- Agent-based modeling methods

Paradigm Shift From Macro to Nano-Spatial Scales for Water Demand Modeling

- Previous water demand models used macro-scale data of overall water use-hard to see changes in demand at this scale
- Conserve Florida Water model uses a bottom up approach that begins with an end use inventory of all water using devices
- Original idea came from research in Boulder

Catalyst for Switching to Bottom Up Approaches for Estimating Demands

- Unsuccessful in quantifying the effects of water conservation on aggregate water use patterns (Buhlig 1995)

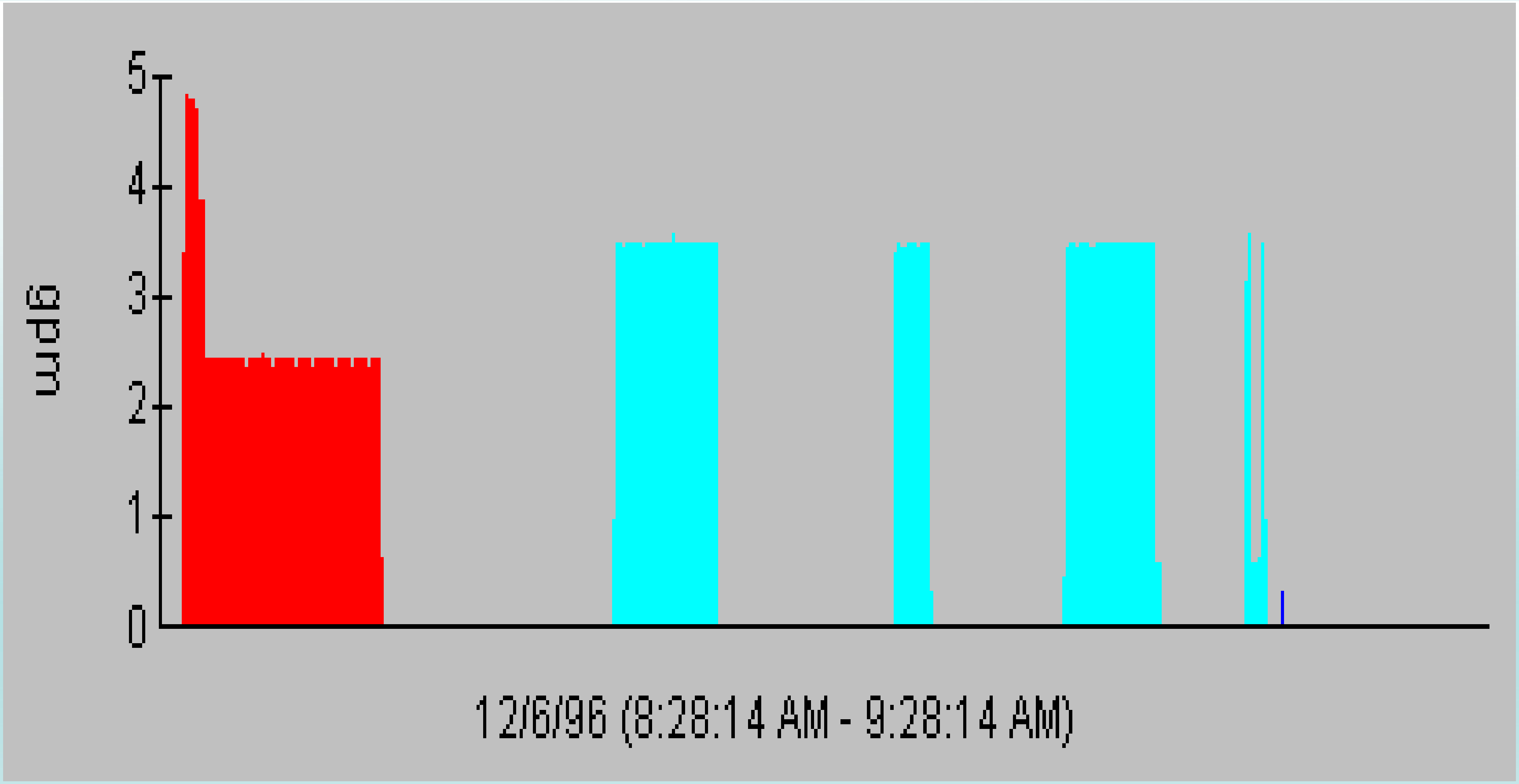


1995-99 Micro-Water Use Studies at the U. of Colorado
Mayer, DeOreo and Heaney

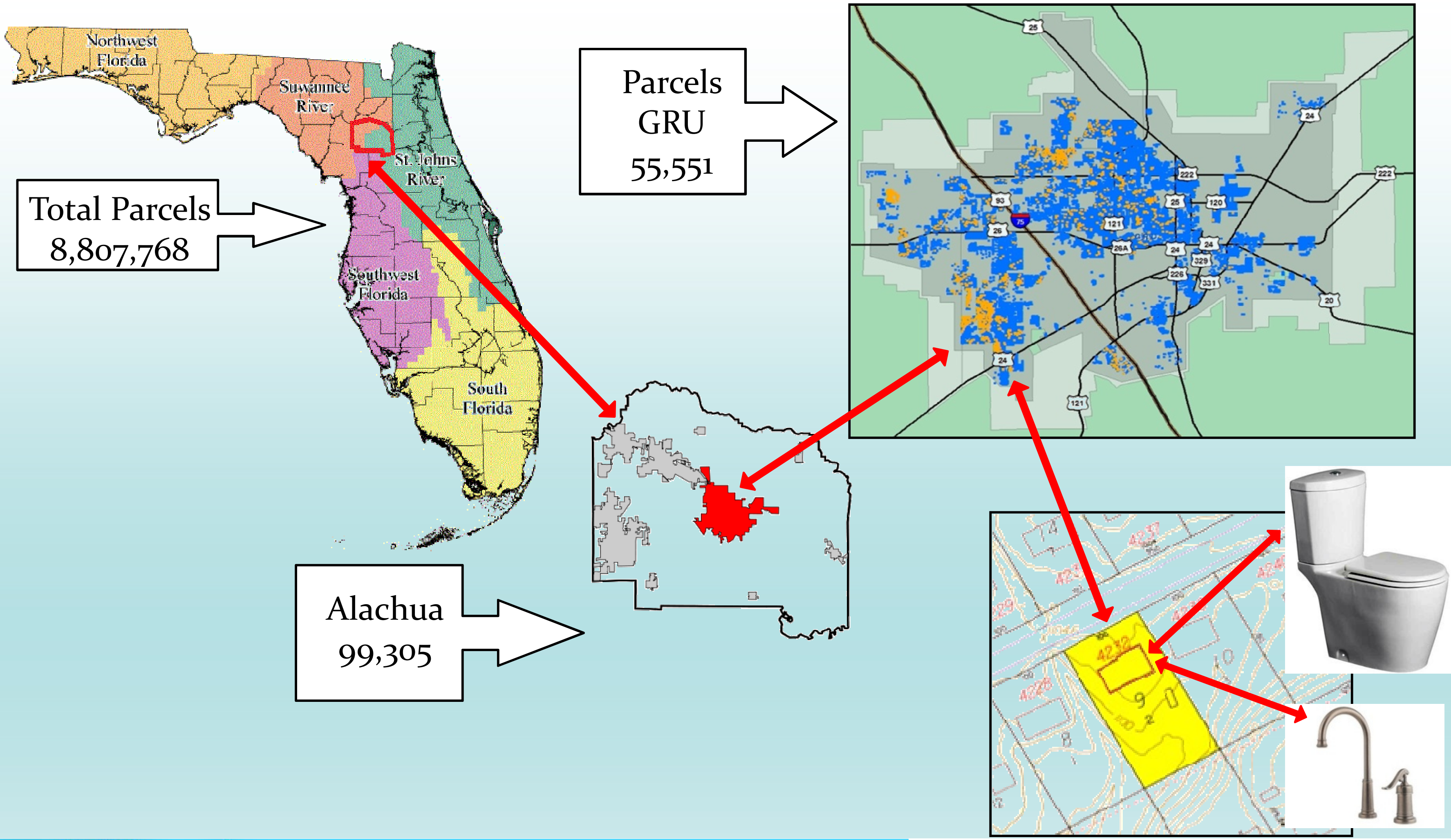
- Sampled 17 houses in a Boulder neighborhood
- Monitored flow to each customer every 10 seconds at the water meter for two weeks
- Developed software to process these high frequency signals into water using events
- Used this method on a national AwwaRF study of 1,200 homes in 12 cities
- First definitive evidence on the nature of residential water use

Water Use Measured Every 10 Seconds
Partition all pulses into water use events

(DeOreo et al. 1996)



Macro to Nano-Scale Evaluation of Urban Water Use is Feasible in Florida



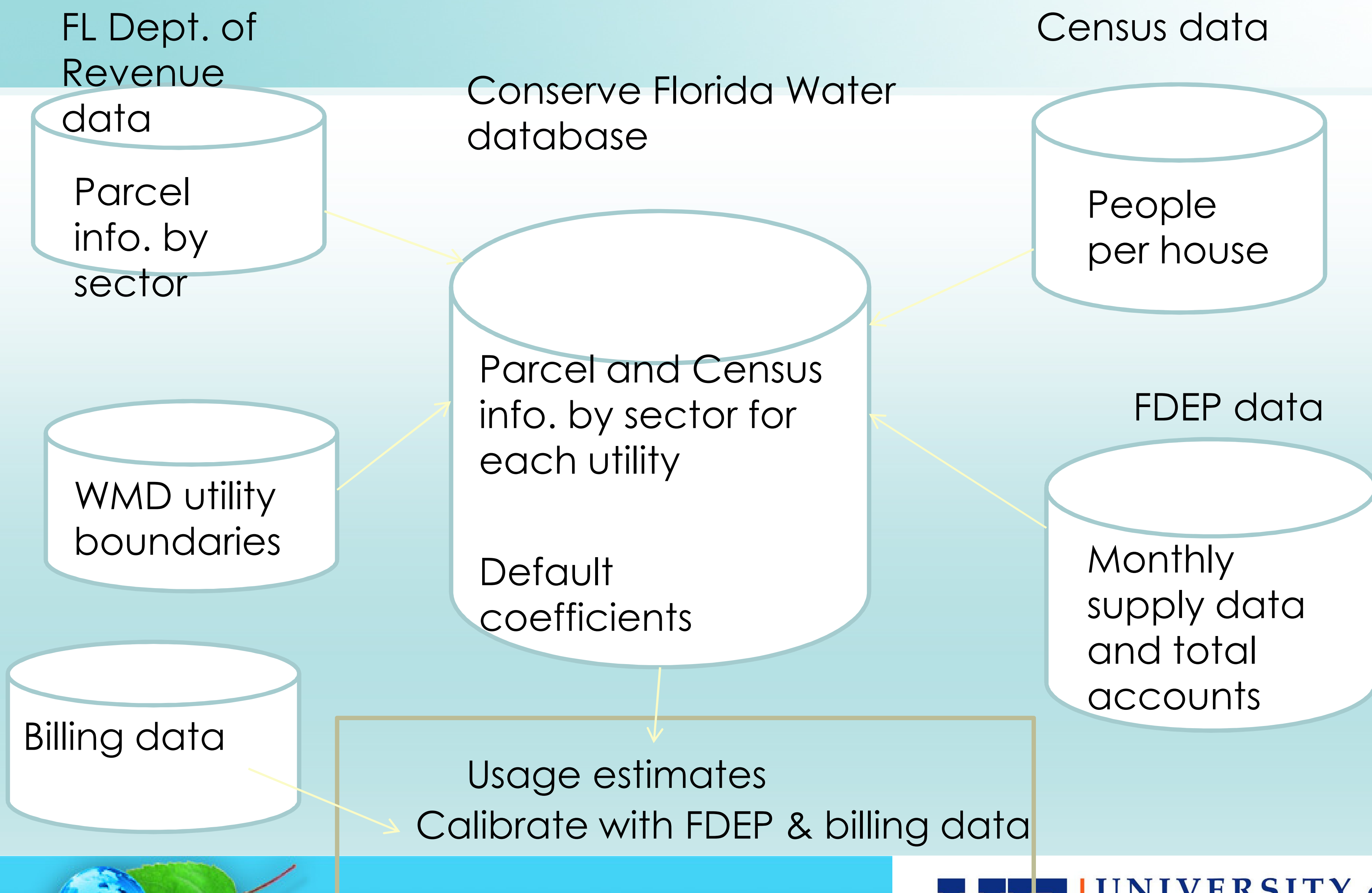
Levels of Spatial Aggregation in Florida Based on 2009 Conditions

Item	Count	Population/no.	Parcels/no.
Population	18,800,000	1	
Parcels	8,800,000	2.14	1
Census blocks	362,500	51.9	24
Traffic analysis zones	12,750	1,475	690
Census tracts*	4,700	4,000	1,872
Water utilities	2,625	7,162	3,352
Counties	67	280,597	131,343

*Count based on 4,000 persons per Census tract.

Friedman et al. (2011)

EZ Guide Databases



EZ Guide Water Use Calibration

Conserve Florida Water Clearinghouse

Promoting Conservation in Our Public Water Supplies

Administration | Su

Home | Profile | Water Supply Analysis | Audit | Water Budget | BMP Analysis | Planning | Summary Report | BMP Tracking |

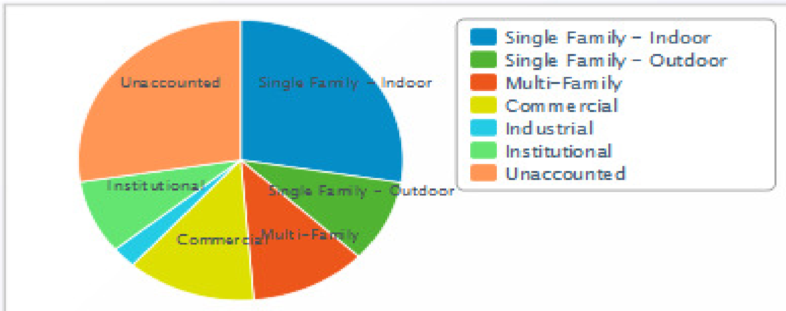
Sanford no billing data

- Historical Conservation Programs
- Historical Conservation Programs (Measures)
- Calibration
- Summary

Water Budget Configurables

Analysis Year: 2009 - To change the Analysis Year return to Water Supply Analysis page

Calibrated Water Budget By Sector



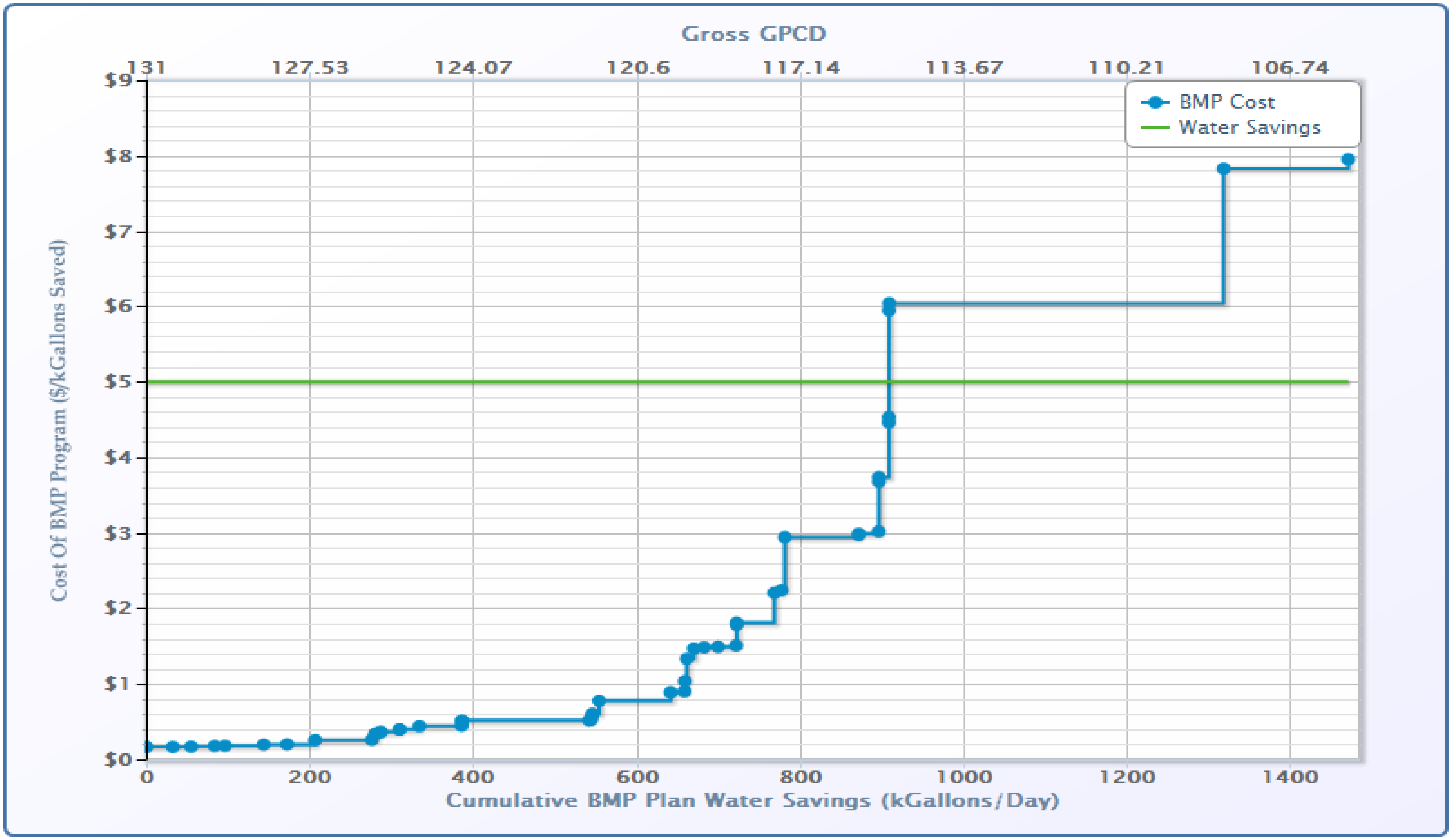
Difference Between FDEP and CFWC Estimate

	FDEP Data	CFWC Estimate	% Difference
Total Accounts	17,729	18,121	2.21 %
Population Served	62,052	57,440	-7.43%
Total Water Use (MGY)	2,674.27	3,247.14	21.42%
GPCD	118	155	31%

Water Use Summary By Sector

Sector	% Water Use	Residential GPCD	Gross GPCD	Average Gallons Per Heated Square Foot Per Month	Links
Single Family	37.1 %	82	57	4.97	
Single Family - Indoor	27.6 %	61	43	3.75	Details
Single Family - Outdoor	9.5 %	21	15	1.31	Details
Multi-Family	11.6 %	59	18	6.26	Details
CII	23.8 %	--	37	3.47	Details
Commercial	12.9 %	--	20	4.45	
Industrial	2.5 %	--	4	0.99	
Institutional	8.5 %	--	13	5.76	
Unaccounted	27.5 %	--	43	--	
Total	**100.0 %**	**--**	**155**	**6.18**	

EZ Guide Optimized Marginal Cost Curve for All Water Conservation BMPs



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Conclusions on Building Bottom Up Watershed/Water Supply/Wastewater/Stormwater/Reuse Systems

- Parcel level databases are available in many areas with vital attribute data
- High frequency water use data are used to isolate individual end use events
- Monthly or more frequent customer billing data provide bases for estimating water and wastewater flows and accounting for impact of irrigation on stormwater runoff
- Directly measured impervious areas greatly improve stormwater modeling capability

Outline

- Why watersheds in urban areas?
- Build your own watershed starting with individual land parcels evaluating centralized vs. decentralized water management options
- **Agent-based modeling methods**

Agent Based Modeling (ABM)

- A bottom up approach is used to evaluate decision processes among affected entities based on a variety of normative and descriptive behavioral assumptions across space and time (Miller and Page 2007)
- Future trends in social science modeling activities in water resources are described by Braden et al. (2009)
- Chu et al. (2009) describe an extensive application of ABM to water demand evaluation in Beijing

Wonderland Creek Watershed in Boulder
(Lee and Heaney 2003)

- GIS is now available for every parcel for stormwater and water use evaluations

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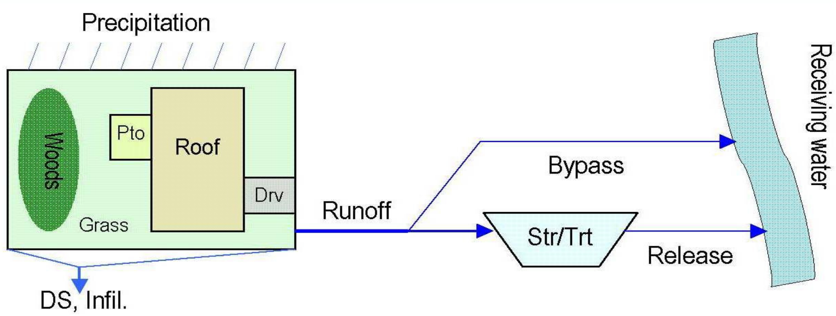
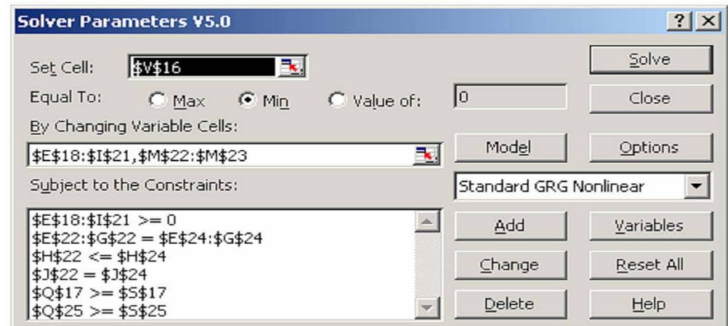
Stormwater Simulation/optimization Model

Lee, Heaney, and Lai (2005)

Now can run for all agents or clusters of agents



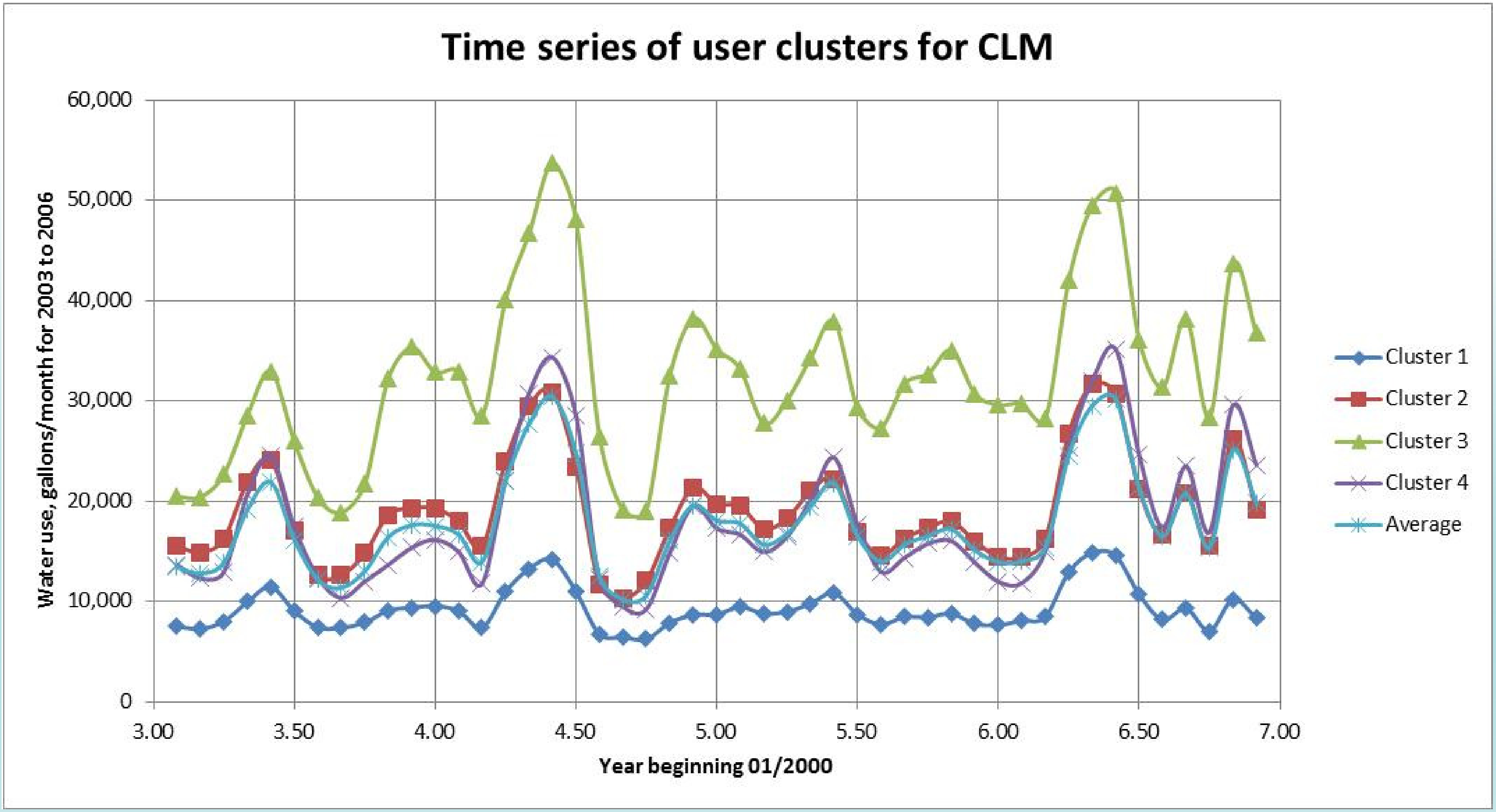


	A	B	C	D	E	F	G	H	I	J	K
1				**Spatial**	Roof	Patio	Drvwy	Yard	TA		
2				**info**	230.51	35.56	45.19	773.467	1084.73		
3							Max Grs	60%			
4											
5			**Land use opt.**		Roof	Patio	Drvwy	Grass	Wood		
6			DS	Opt1	2.7	2.7	1.037	13.5	33.9		
7			(mm)	Opt2	9	7	12.7	22.8	41.6		
8				Opt3				32.5	55		
9				Opt4					118.5		
10			Unit	Opt1	$0.00	$0.22	$0.65	$1.51	$8.61		
11			Cost	Opt2	$16.15	$0.31	$0.86	$2.69	$15.07		
12			($/m2)	Opt3				$3.66	$21.53		
13				Opt4					$32.29		
14			Land	Opt1	1	1	1	1	1		
15			use	Opt2	1	1	1	1	1		
16			Opt	Opt3				1	1		
17				Opt4					1		
18			Land	Opt1	230.51	0	0	464.08	309.387		
19			use	Opt2	0	35.56	45.19	0	0		
20			Opt	Opt3	0	0	0	0	0		
21				Opt4	0	0	0	0	0	Yard	
22					230.51	35.56	45.19	464.08	309.387	773.467	
23					=	=	=	=<		=	
24				Area	230.51	35.56	45.19	464.08		773.467	
25				**DS**	2.7	7	12.7	13.5	33.9		

	L	M	N	O	P	Q	R	S	T	U	V
1	**Evapo. rate**			**Infiltration rate**							
2	Month	(mm/d)		Infiltr	1.27	(mm/hr)					
3	1	0.381		Del-T	1	(hr)					
4	2	0.457									
5	3	0.635		**Pollutant Removal** (1st order PF)					**Cost fnc** = a (Str)^c		
6	4	0.991		Cout = Cin * exp(-k * td)					Storage	a	b
7	5	1.651		Cin	10	(mg/L)			On-site	1000	0.6
8	6	2.515		k	0.04	(/hr)			Off-site	10000	0.7
9	7	3.226									
10	8	3.150									
11	9	1.600			**Volume-based**					**Total cost**	
12	10	1.092			Prcp	317.5					Cost
13	11	0.686			DS	216.45				Land	$3,414
14	12	0.381			Rff	101.05				On-Str	
15					Str/Trt	40.42				Off-Str	$24,646
16	**On-site str**				BP	60.63		Target		Total	$28,061
17	Max A	2%	of TA		Capt	40.0%	>=	40.0%			
18	Max A	21.69	(m2)								
19	Max D	0.1	(m)		**Pollutant mass**						
20					Mrff	1010.45					
21	**Off-site str/rls**				Min	404.181					
22	Storage	3.62783	(mm)		Mbp	606.271					
23	Release	0.0221	(mm/h)		Mout	50.52					
24	Empty	6.84002	(d)		Mrv	353.658		Target			
25					Rm	35.0%	>=	35.0%			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
26	**Continuous Simulation**																					
27	Total =	317.5													101.045				40.4181	60.6271		50.5232
28	Prcp time series		Dry	ET	DS for each area					Runoff from each area					Overall	Storage-Release-Bypass					Pollutant removal	
29	Time	Prcp	Dry	ET	DSr	DSp	DSd	DSg	DSw	Rff-r	Rff-p	Rff-d	Rff-g	Rff-w	Rff	Str1	Rls	Str2	Trt	BP	td	Mout
30		(mm)	day	(mm/d)	avail	avail	avail	avail	avail									0			(hr)	
31	2000/01/04 12:00	2.54	0	0.381	2.7	7	12.7	13.5	33.9	0	0	0	0	0	0	0	0	0	0	0	0	0
32	2000/01/18 11:00	2.54	13.917	0.381	2.7	7	12.7	13.5	33.9	0	0	0	0	0	0	0	0	0	0	0	0	0
33	2000/01/26 19:00	2.54	8.2917	0.381	2.7	7	12.7	13.5	33.9	0	0	0	0	0	0	0	0	0	0	0	0	0
34	2000/01/26 22:00	2.54	0.0833	0.381	0.19175	4.49175	10.1917	10.9917	31.3917	2.34825	0	0	0	0	0.49902	0.49902	0.0221	0.47692	0.49902	0	11.2903	3.17674
35	2000/01/27 02:00	2.54	0.125	0.381	0.04763	1.99937	7.69937	8.49937	28.8994	2.49238	0.54063	0	0	0	0.54737	0.95798	0.0221	0.93588	0.54737	0	33.9648	1.40685
36	2000/02/15 05:00	2.54	19.083	0.4572	2.7	7	12.7	13.5	33.9	0	0	0	0	0	0	0	0	0	0	0	42.349	0
131	2000/09/24 14:00	2.54	0	1.6002	0	0	0	0	0	2.54	2.54	2.54	1.27	1.27	1.27219	3.62783	0.0221	3.60574	0.0221	1.25609	163.66	0.00032
132	2000/09/24 15:00	5.08	0	1.6002	0	0	0	0	0	5.08	5.08	5.08	3.81	3.81	3.08773	3.62783	0.0221	3.60574	0.0221	3.06563	163.66	0.00032
133	2000/12/05 19:00	2.54	72.125	0.381	2.7	7	12.7	13.5	27.4796	0	0	0	0	0	0	0	0	0	0	0	163.16	0
134	2000/12/10 21:00	2.54	5.0417	0.381	2.08088	6.38088	12.0809	12.8809	26.8605	0.45912	0	0	0	0	0.09757	0.09757	0.0221	0.07547	0.09757	0	2.20745	0.89321
135	2000/12/22 13:00	2.54	11.625	0.381	2.7	7	12.7	13.5	28.7496	0	0	0	0	0	0	0	0	0	0	0	3.41489	0

Four Temporal Water Use Clusters and Overall Average



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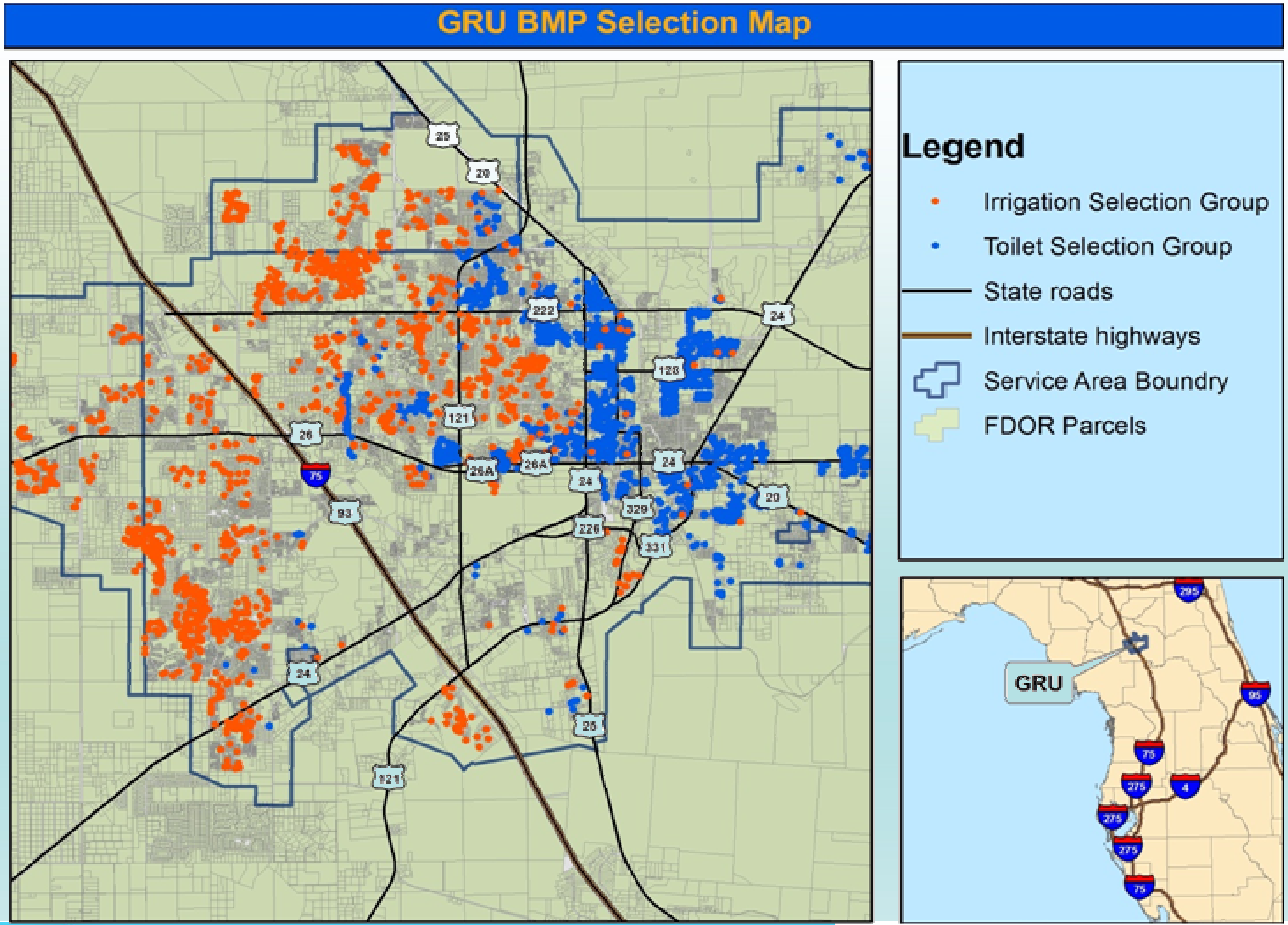
Spatial Clusters Based on Bottom Up Optimization
Selected priority irrigation and toilet retrofit parcels



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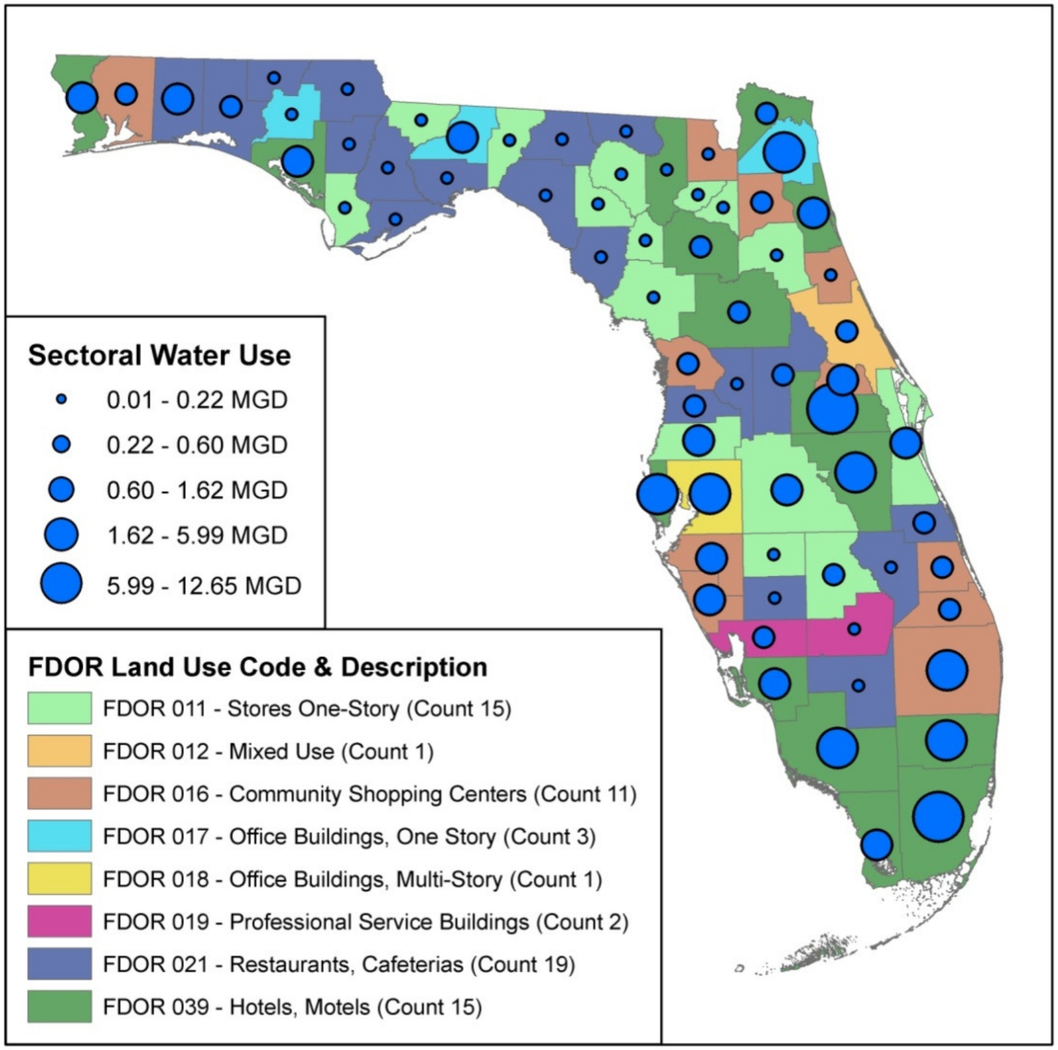
Upscale to the State
Top Commercial Water Use Sectors by County



- The top water using commercial sectors vary significantly by county
- Similar result for industrial sectors
- Non-residential water use is heterogeneous and site specific

Summary and Conclusions

- Why watersheds in urban areas? Yes but need to concurrently look at associated water, wastewater, stormwater, and reuse networks
- Build your own bottom up network models
- Agent-based modeling methods are used to target clusters of parcels to find more sustainable combinations of centralized and decentralized systems
- Need increased emphasis on customer behavior in water demand characterization

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