Developing a Threat Assessment and Monitoring Framework for Urban Karst Groundwater Management

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Committee:

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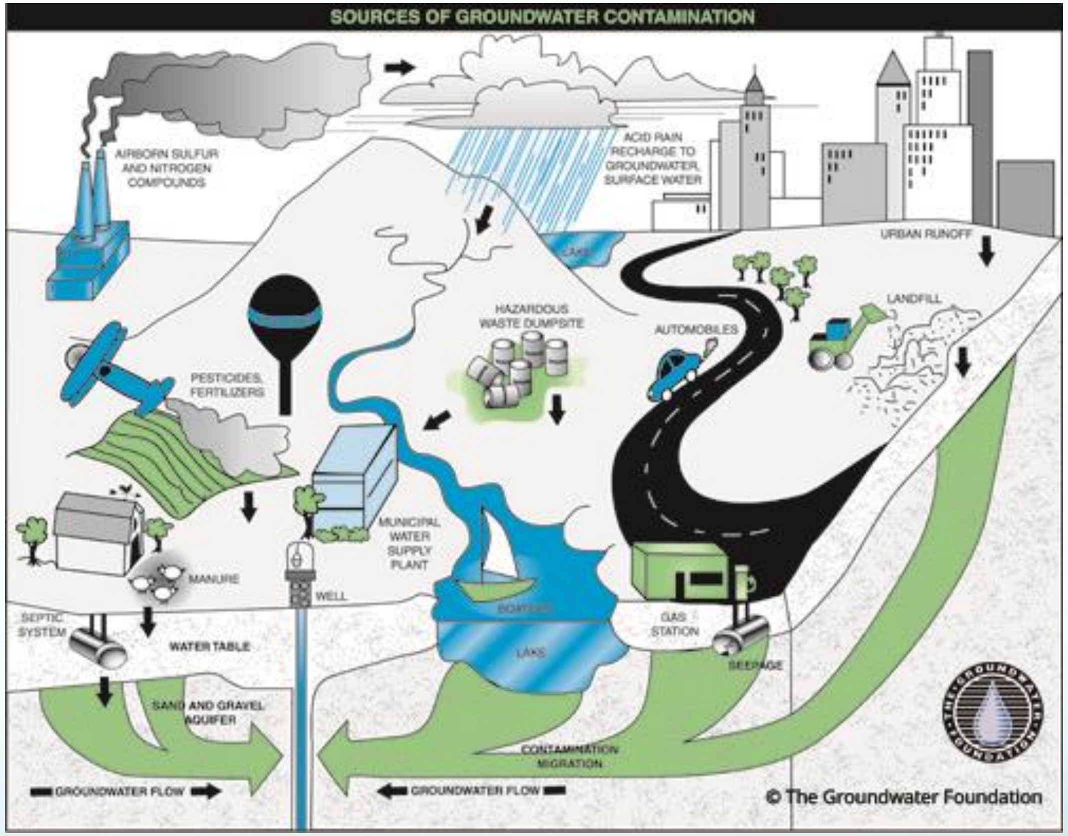
Introduction

- Current world population is about seven billion people
- Majority of people live in urban areas posing a threat to groundwater quality, especially in urban karst settings
- Tools for evaluation and management exist but there is evidence of recently contaminated groundwater
- This study’s purpose is to create a holistic, data-driven monitoring framework for urban karst groundwater systems



Groundwater Contamination (2016)

Research Questions

- **Can an effective monitoring framework for urban karst groundwater quality be developed from historic and modern data in an urban karst setting?**
  - What indicators, parameters, and data quality are needed to create an effective holistic monitoring framework for urban karst groundwater?
  - In an urban karst region what parameters need to be prioritized for effective monitoring and management to meet the resources of interested stakeholders?

Literature Review

- One fourth of the global population resides on or near a karst landscape (Ford and Williams 2007)
  - Urbanization is responsible for polluting karst aquifers
  - Polluted groundwater have negative impacts on the ecosystem and communities
- Karst regions have been evaluated and managed with little consideration of urban karst groundwater
  - Groundwater quality issues still present

Evaluation Approach	Management Approaches
Karst Disturbance Index (van Beynen and Townsend 2005)	International Groundwater Management Plans (Huppert 1995; LaMoreaux et al. 1997; Kačaroğlu 1999; Force 2000; Escolero et al. 2002; Polemio et al. 2009b; Bakalowicz 2011; Parise et al. 2015b)
Karst Aquifer Vulnerability Index (van Beynen et al. 2012c)	EPA Clean Water Act
Karst Sustainability Index (van Beynen et al. 2012b)	Safe Drinking Water Act
DRASTIC (Aller et al. 1987)	Underground Injection Control Program (EPA 1999)
EPIK (Doerfliger et al. 1999)	Federal Cave Resource Protection Act of 1988
Karst Feature Inventory/ Database (Farrant and Cooper 2008)	National Cave and Karst Research Institute Act of 1998
Hydrogeological Environmental Impact Statement (Brinkmann and Parise 2012)	Local Regulations such as Best Management Plans
	Kentucky Groundwater Protection Plan (KAR 1994)
	Stormwater Quality Management Plan
	MS4 Phase I and Phase II
	Minimum Control Measures (MCMs)

Literature Review

- Karst Groundwater Quality
  - Negatively Impacted by human actions
  - Urban groundwater is extremely sensitive to landuse change
  - Reduction of natural infiltration and the occurrence of "First Flush" events
  - Rapid transport of pollutants through karst groundwater
  - Urban influence has provided potential for antibiotic resistance genes in bacteria

Common Groundwater Pollutants	
Light Non-aqueous Phase Liquids Less-dense than Water (Vesper et al. 2001; Nedvidek 2014)	Dense Non-aqueous Phase Liquids More-dense than Water (Vesper et al. 2001; Nedvidek 2014)
Trash and other debris	Metals
Sediment	Industrial Runoff
Pathogens	Urban Runoff
Chemicals, Anions (Nitrates, phosphate, chloride, etc.)	Antibiotic Resistant Genes/ "Superbugs" (Devarajan et al. 2016)
Pharmaceuticals and Personal Care Products (Gavrilescu et al. 2015)	Leaking Sewage
Microbiological pollutants (Göppert and Goldscheider 2008; Muller et al. 2013)	Enteric Bacteria (Kelly et al. 2009)

Literature Review

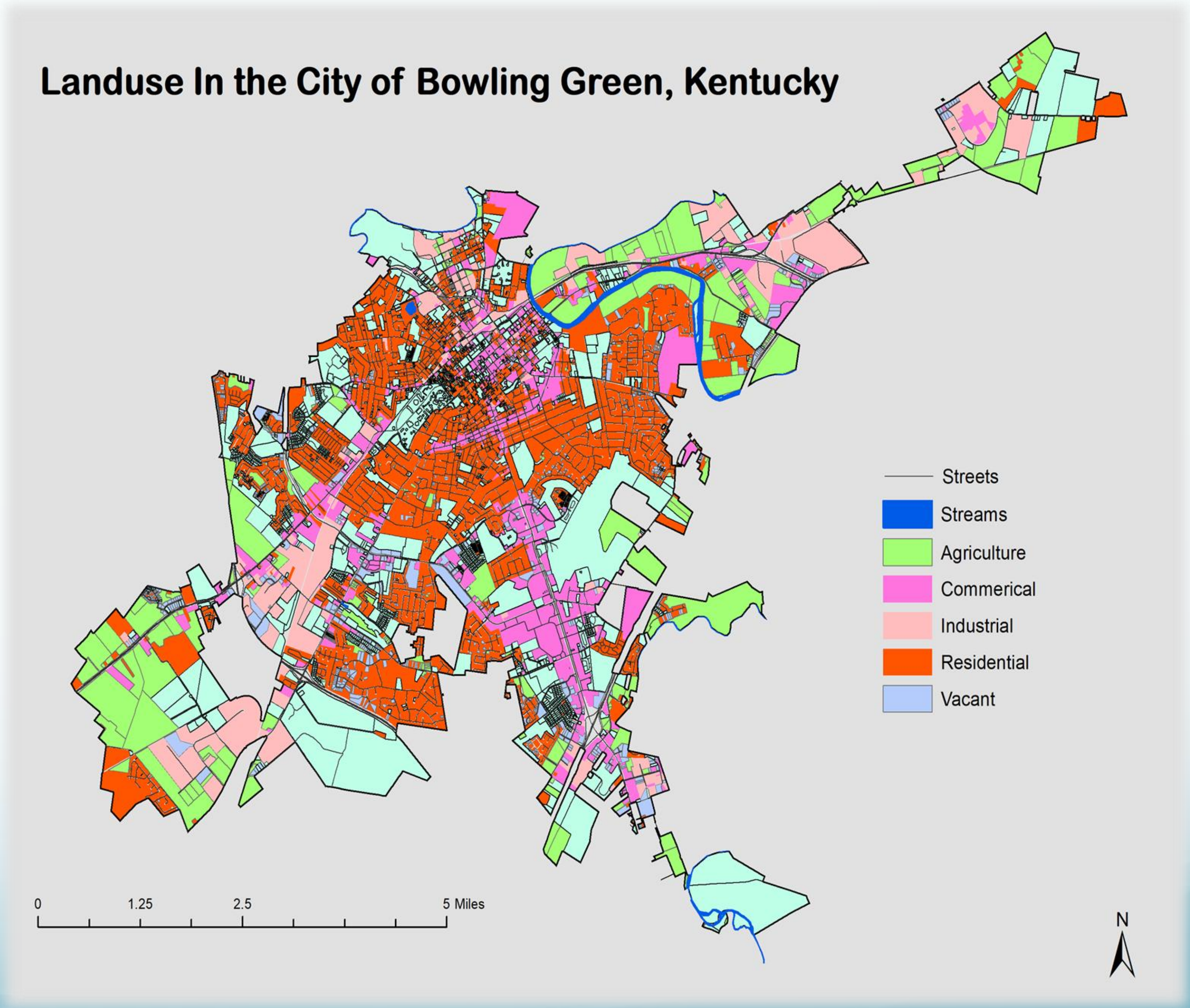
- The city of Bowling Green, Kentucky (CoBG) has extensive research on the interaction of urbanization and karst groundwater
  - The CoBG used caves as a "natural sewer" (Mace 1921)
  - Over 2,000 known injection wells in the City
  - Intense remediation and understanding has occurred, but there are still groundwater quality issues (Groves 1987; Crawford 1989; Cesin and Crawford 2005)
  - The CoBG has over 40 years of historical groundwater data that can be used to develop future planning and management

Study Area: Bowling Green, KY

- Third largest city in Kentucky
- Largest city to be built upon a karst sinkhole plain and an individual cave system (Crawford 1985).
- Population: 65,234
- Average Precipitation: 131 cm annually
- Average Temperature: 13.9°C
- Geology: St. Louis, St. Genevieve, and Girkin limestone

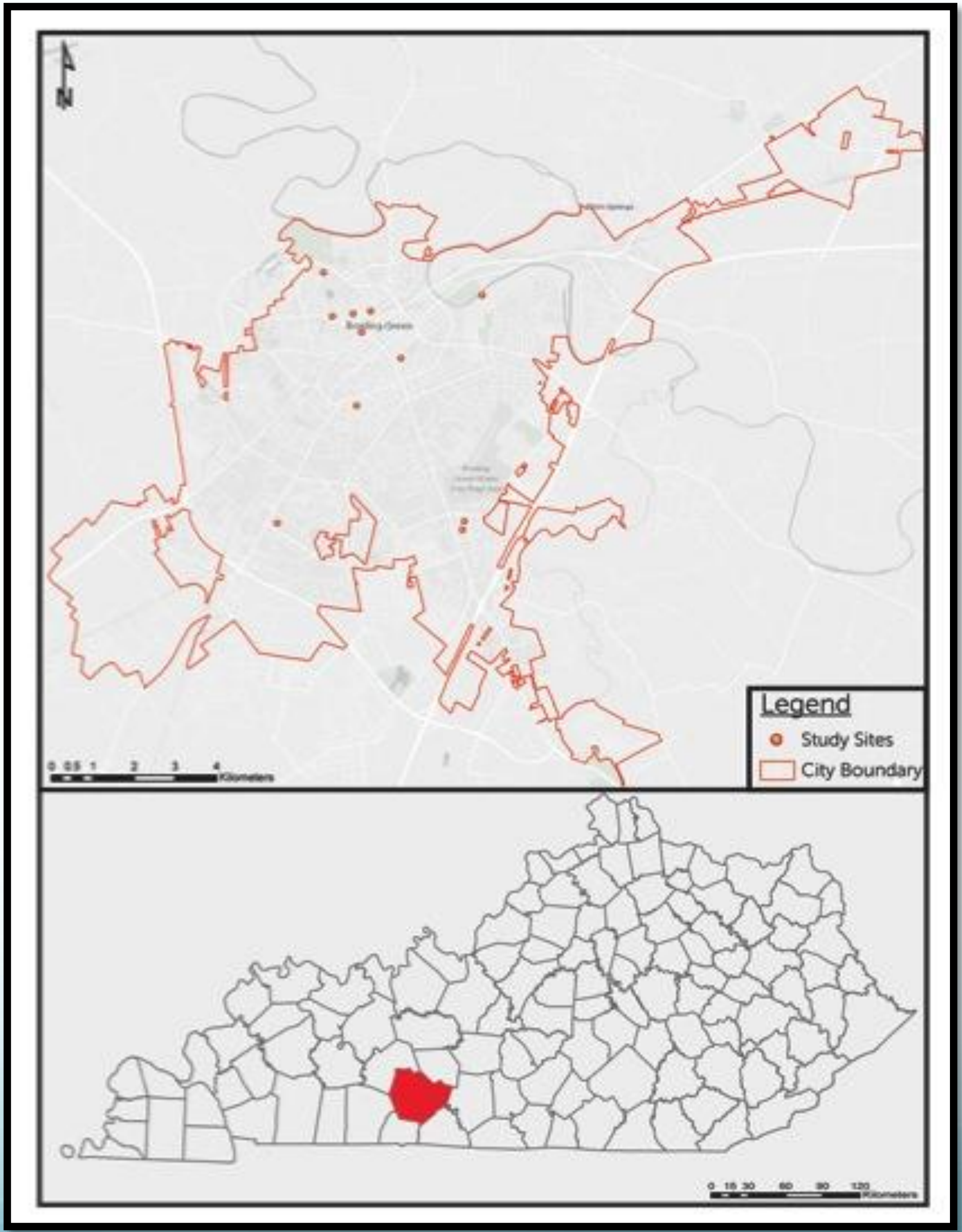
By: Gary Berdeaux

Study Area



Landuse In the City of Bowling Green, Kentucky
Streets
Streams
Agriculture
Commerical
Industrial
Residential
Vacant
0
1.25
2.5
5 Miles
N

Study Area



Methods Overview

1. Historical Data Evaluation and Review
2. Primary Data Collection in CoBG
3. Development of Urban Karst Groundwater Framework
4. Testing and Validation of the Framework

Methods: Historical Data Review

Historical Data Evaluation and Review

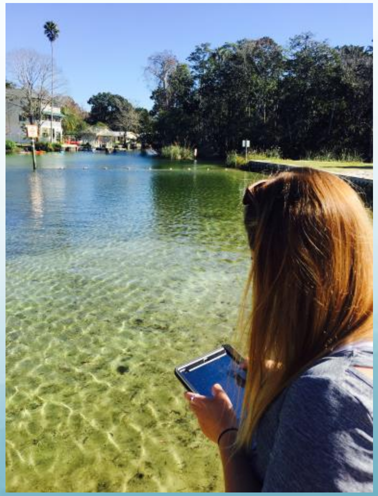
- Collect and Categorize all historic data:
  - Studies conducted by Crawford (1989) and Crawford et al. (1987)
  - Quarterly sampling data from the City's Public Works department
  - Past studies conducted by faculty and graduate students from WKU
  - Any other secondary data that are available

Categories
Sampling Resolution
No data collection/ monitoring
Data collection on a quarterly basis
Data collection on a monthly basis
Data collection on a bi-weekly basis
weekly data collection
Ten-minute resolution
Real-time resolution
Potential Parameters
Reference Table in Previous Slide
Sampling Location
Spring
Cave
Surface Stream
Bluehole
Sinkhole
Injection Wells
Data Source
Primary data
Secondary data
Indicator results
Water quality samples that are over the MCM or regulation standards
Improvements
Change over time of parameters
Improved regulations/management

Methods: Ancillary Data Collection and Management

Primary Data Collection in CoBG

- Urban Karst Groundwater GIS Geodatabase
  - A site specific monitoring and management tool
  - Visual representation of highly contaminated and vulnerable areas
  - Developed Threat and Monitoring assessment layers
    - Karst features received a threat and a monitoring score, which helps determine sampling sites



Methods: Ancillary Data Collection and Management

Primary Data Collection in CoBG

Category	Scoring
Feature Type	Cave Stream Conduit Flow Spring Diffuse Flow Spring Resurgence Karst Window Injection Well Sinkhole Surface Stream Sinking Stream Monitoring Well Other (fillable)
County	
City	
Infrastructure	
Flooding	0= None 2= Unknown 4= Yes
Saltwater Intrusion	0= None 2= Unknown 4= Yes
Pollution Disturbance Proximity	0= Absent or > 1km 2= Within 0.5 km 4= On site
Heavy Metals	0= None 2= Unknown 4= Yes
Pesticides/Herbicides	0= None 2= Unknown 4= Yes

Novel Pollutants	0= None 2= Unknown 4= Yes
Nutrients	0= None 2= Unknown 4= Yes
Industrial Pollutants	0= None 2= Unknown 4= Yes
Microbiological Pollutants	0= None 2= Unknown 4= Yes
Fuel-related Chemicals	0= None 2= Unknown 4= Yes

Residential Landuse	0= None 2= Unknown 4= Yes
Industrial Landuse	0= None 2= Unknown 4= Yes
Commercial Landuse	0= None 2= Unknown 4= Yes
Parks/Golf Course/Recreational Landuse	0= None 2= Unknown 4= Yes

Protected by Regulation	**0= Local/State/Federal Combo** **1= Federal** **2= State** **3= Local** **4= No**
Protected by Other (fence, BMP, etc.)	0= Yes, comprehensive 2= Limited protection 4= None
Sensitive Biota	0= None 2= Unknown 4= Yes
Feature Modification	0= None 2= Limited 4= Significant
Nonpoint Source Pollution	0= None 2= Unknown 4= Yes
Point Source Pollution	0= None 2= Unknown 4= Yes
Impervious Surface Cover	0= Absent or > 1km 2= Within 0.5 km 4= On site
USTs	0= None 2= Unknown 4= Yes
Landfill Landuse	0= None 2= Unknown 4= Yes

Parking Lot Cover Landuse	**0= None** **1= Residential** **2= Commercial/ Residential** **3= Commercial/Industrial** **4= All**
Roads and Traffic	0= None 1= Dirt/ Recreational 2= Residential/ Commercial 3= Commercial/ Highway 4= All
Population Density in Basin	0= Low 2= Moderate 4= High
Site Monitoring	0= Real-time Monitoring 1= Weekly Sampling 2= Monthly/Quarterly Sampling 3= Random Sampling 4= None
Delineated Drainage Basin	0= None 2= Unknown 4= Yes
Retention Basins/Surface Stormwater Infrastructure	0= None 2= Unknown 4= Yes

Threat Evaluation

Methods: Ancillary Data Collection and Management

Primary Data Collection in CoBG

Category	Scoring
Feature Type	Cave Stream Conduit Flow Spring Diffuse Flow Spring Resurgence Karst Window Injection Well Sinkhole Surface Stream Sinking Stream Monitoring Well Other (fillable)
County	
City	
Infrastructure	
Flowing	0 = No 4 = Yes
Water Present	0 = No 4 = Yes
Flows to Surface Stream	0 = No 4 = Yes
Flood Monitoring	0= None 2= Unknown 4= Yes
Discharge Monitoring	0= No 2= Unknown 4= Yes
Known Inputs (Tribs)	0 = No 4 = Yes

Delineated Basin	0= No 2= Unknown 4= Yes
Regulatory Monitoring Required	0= No 2= Unknown 4= Yes
Sensitive Biota	0 = Yes 2= Unknown 4 = No
Feature Modification	0 = Significant 2= Limited 4 = None
Historical Data	0 = No Data 1= 1 year or < 2= < 5 years 3= 10 years or > 4= 10 years or > & Current Data

Monitoring Data Resolution	**0 = None** **1= Random Sampling** **2= Monthly/Quarterly Sampling** **3= Weekly Sampling** **4= Real-time Monitoring**
Accessibility	0 = None 1 = Private 2= Limited 3 = Public/ Permit 4 = Yes
Dye-traced	0= No 2= Unknown 4= Yes
Available Precip Data	0 = None 1 = Historic 2= Limited 3 = Current 4 = Current and Historic
Water Level Data	0 = None 1 = Historic 2= Limited 3 = Current 4 = Current and Historic
Existing Monitoring	0 = None 1= Quarterly Monitoring 2= Monthly Monitoring 3= Weekly Monitoring 4 = Real-time Monitoring
Direct Aquifer Connection	0= No 2= Unknown 4= Yes
Potential Storm Sampling Site	0= No 2= Unknown 4= Yes
Site Monitoring Applicable	0= No 2= Unknown 4= Yes

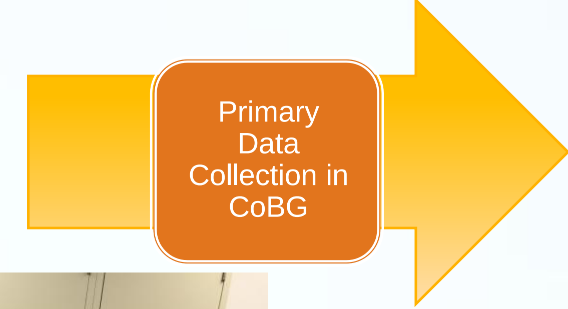
Monitoring Evaluation

Methods: Case Study and Primary Data Collection

Primary Data Collection in CoBG

- Verification and application of a karst feature inventory (KFI)
- Application of Threat/Monitoring Assessment in BG
- Water quality parameters are in the process of being collected for 6-9 months

Methods: Case Study and Primary Data Collection



Sample Parameters	
Oil and Grease	*E.coli*
Antibiotic Resistant Genes	Legionella Bacteria
Biological Oxygen Demand	Chemical Oxygen Demand
Total Carbon	Anions
Metals	Total Chlorine
pH	Temperature
Specific Conductivity	Turbidity
Total Suspended Solids	Dissolved Oxygen

Sample Sites	
Whiskey Run Spring	Barren River
927 Payne Injection Well	1126 Vine Injection Well
Durbin Estates Injection Well	New Spring
Lost River Rise	Lost River Spring
Carver Well Cave	By-Pass Cave Well

Methods: Case Study and Primary Data Collection

Primary Data Collection in CoBG

Date	Fluoride	Chloride	Nitrite	Bromide	Nitrate	Phosphate	Sulfate	O&G	BOD	COD	TOC	E.coli
2/14/18	0.19	11.14	0.59	0.86	23.75	1.8	7.2	1.48	0.4	5	10.7	120
2/21/18	0.12	10.01	0.54	0.83	23.58	1.68	6.93	2.37	1.08	10	9.823	473
2/28/18	0.18	8.87	0.7	0.77	20.81	1.59	6.76	0.87	0.57	6	10.85	201
3/7/18	0.2	8.91	0.58	0.92	24.71	1.97	5.83	0.87	0.79	5	26.08	52
3/14/18	0.22	10.97	0.56	0.84	22	1.7	6.02	2.5	0.49	8	10.31	148
3/21/18	0.22	15.52	0.51	0.75	20.1	1.45	6.45	2.78	0.31	1	13.64	417
3/28/18	0.15	11.15	0.42	0.75	16.76	1.45	7.87	7.31	0.71	8	15.49	292
4/4/18	0.15	9.95	0.46	0.69	18.47	1.52	7.14	2.84	0.51	5	16.28	487
4/11/18	0.14	9.23	0.65	0.78	21.76	1.82	5.92	2.63	0.52	0	10.33	74
4/15/18	0.19	10.49	0.55	0.8	12.86	1.91	6.96	2.04	0	0	8.79	908
4/18/18	0.14	10.04	0.6	0.68	18.47	1.77	7.04	1.81	0.33	0	7.98	292
4/25/18	0.17	8.49	0.58	0.76	15.84	1.65	6.7	1.94	0.73	0	10.44	576
5/2/18	0.15	9.95	0.46	0.69	18.47	1.52	7.14	1.45	0.43	0	10.4	31
5/9/18	0.12	8.73	0.16	0.34	20.1	1.05	5.93	1.63	0.65	0	13.76	226
5/16/18	0.05	8.52	0.15	0.32	21.09	0.71	5.46	2.4	0.38	0	13.64	121
5/23/18	0.15	15.15	0.07	0.34	13.63	0.69	5.89	3.78	1.12	0	19.33	1046

Lost River Rise Preliminary Results

Methods: Case Study and Primary Data Collection

Primary Data Collection in CoBG

Date	Fluoride	Chloride	Nitrite	Bromide	Nitrate	Phosphate	Sulfate	O&G	BOD	COD	TOC	E.coli
2/14/18	0.13	50.01	0.7	0.86	2.91	1.82	15.67	5.34	9.84	158	28.57	4106
2/21/18	0.12	51.76	0.63	0.84	6.71	1.69	36.68	5.8	11.59	191	31.87	2224
2/28/18	0.14	3.97	0.7	0.77	1.38	1.56	3.75	4.8	5.31	20	9.69	3654
3/7/18	0.3	18.07	0.58	0.92	10.29	1.92	17.12	1.53	3.97	0	16.36	146
3/14/18	0.18	289.54	0.74	0.84	5.94	1.69	27.05	0.43	2.25	12	11.28	62
3/21/18	0.27	26.48	0.5	0.75	9.99	1.49	15.44	10.8	2.06	5	15.6	426
3/28/18	0.12	12.52	0.42	0.74	6.45	1.45	8.83	2.44	4.08	14	14.83	759
4/4/18	0.22	15.43	0.46	0.68	8.53	1.53	12.32	9.33	3.72	14	9.67	318
4/11/18	0.28	18.73	0.65	0.79	11.11	1.88	17.35	2.3	2.33	0	13.08	41060
4/15/18	0.25	13.61	0.55	0.8	7.21	1.93	10.15	3.38	1.35	0	10.51	771
4/18/18	0.22	16.69	0.61	0.68	9.17	1.76	15.58	3.73	1.32	0	11.03	233
4/25/18	0.23	17.19	0.59	0.76	8.89	1.68	15.17	7.65	2.16	0	14.36	158
5/2/18	0.22	15.43	0.46	0.68	8.53	1.53	12.32	3.17	1.9	0	14.2	4106
5/9/18	0.16	15.75	0.16	0.35	9.06	1.07	14.54	5.54	2.58	2	12.3	146
5/16/18	0.18	3.59	0.21	0.32	0.91	0.68	13.78	3.97	6.46	13	17.89	52
5/23/18	0.15	18.05	0.07	0.34	11.1	0.79	12.32	3.41	2.43	0	24.46	794

By-Pass Cave Well Preliminary Results

Methods: Case Study and Primary Data Collection

Primary Data Collection in CoBG

Date	Fluoride	Chloride	Nitrite	Bromide	Nitrate	Phosphate	Sulfate	O&G	BOD	COD	TOC	E.coli
2/14/18	0.13	32.16	0.73	0.86	2.42	1.78	9.11	2.47	9.44	195	29.81	97
2/21/18	0.35	16.45	0.55	0.82	2.75	1.74	7.19	6.6	10.28	175	25.48	4611
2/28/18	0.44	5.03	0.73	0.77	2.1	1.85	3.44	5.93	26.09	100	15.25	2755
3/7/18	20.16	8.29	0.6	0.92	1.05	2	1.17	3.26	83.7	386	102.6	959
3/14/18	0.44	5.29	0.55	0.83	1.11	1.77	2.87	5.38	15.88	35	18.81	75
3/21/18	0.17	10.86	0.52	0.74	5.53	1.47	31.06	4.51	9.89	75	14.65	8164
3/28/18	0.07	2.89	0.44	0.74	2.15	1.78	6.6	4.3	10.27	100	15.4	1054
4/4/18	1.06	2.86	0.51	0.67	1.59	1.75	2.59	5.15	63.48	120	32.61	9804
4/11/18	1.85	7.14	0.65	0.79	0.95	1.83	1.63	11.85	4.76	226	37.82	1658
4/15/18	0.29	2.21	0.55	0.8	2.13	2.14	6.29	3.76	62.99	27	8.48	4611
4/18/18	1.35	7.22	0.6	0.68	1.84	1.98	1.64	9.77	37.56	162	21.91	1968
4/25/18	0.55	10.07	0.91	0.76	7.7	1.65	38.22	4.79	13.65	5	19.77	20
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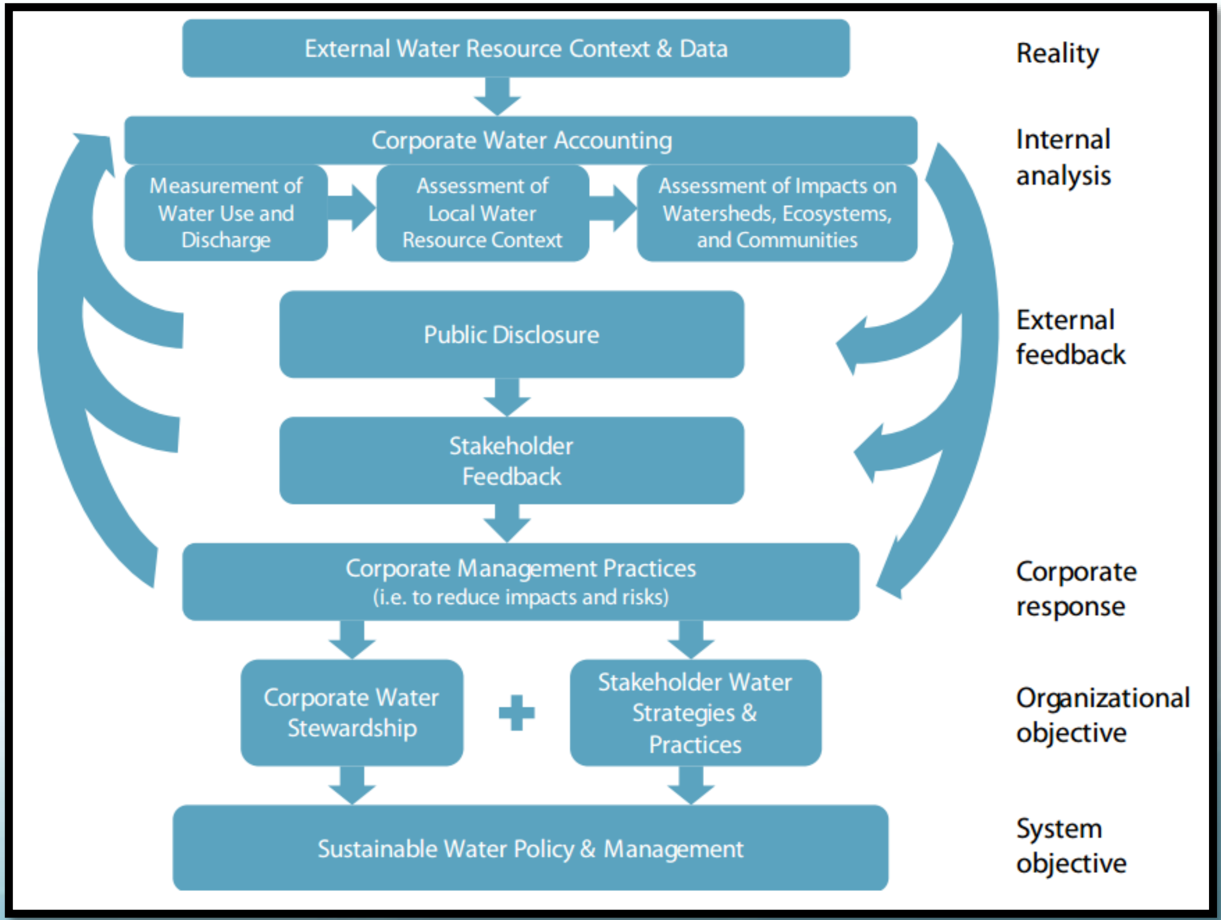
5/9/18	2.49	3.13	0.16	0.35	0.65	1.2	1.68	4.27	59.87	95	37.91	2909
5/16/18	2.44	4.08	0.15	0.34	0.87	0.72	0.58	5.74	65.27	167	58.35	1789
5/23/18	1.2	2.5	0.07	0.33	0.67	0.96	1.54	14.15	27.15	139	48.16	4352

1126 Vine Street Injection Well Preliminary Results

Methods: Development of the Framework

Development of Urban Karst Groundwater Framework

- A framework is not a model or a method, but the steps in-between
  - Data-driven decision making tool will be developed that can be utilized for monitoring and management
  - Inputs and outputs will be determined from literature, existing tools, and both historic and primary data
  - The CoBG will be used as a case study to develop a groundwater monitoring and management framework



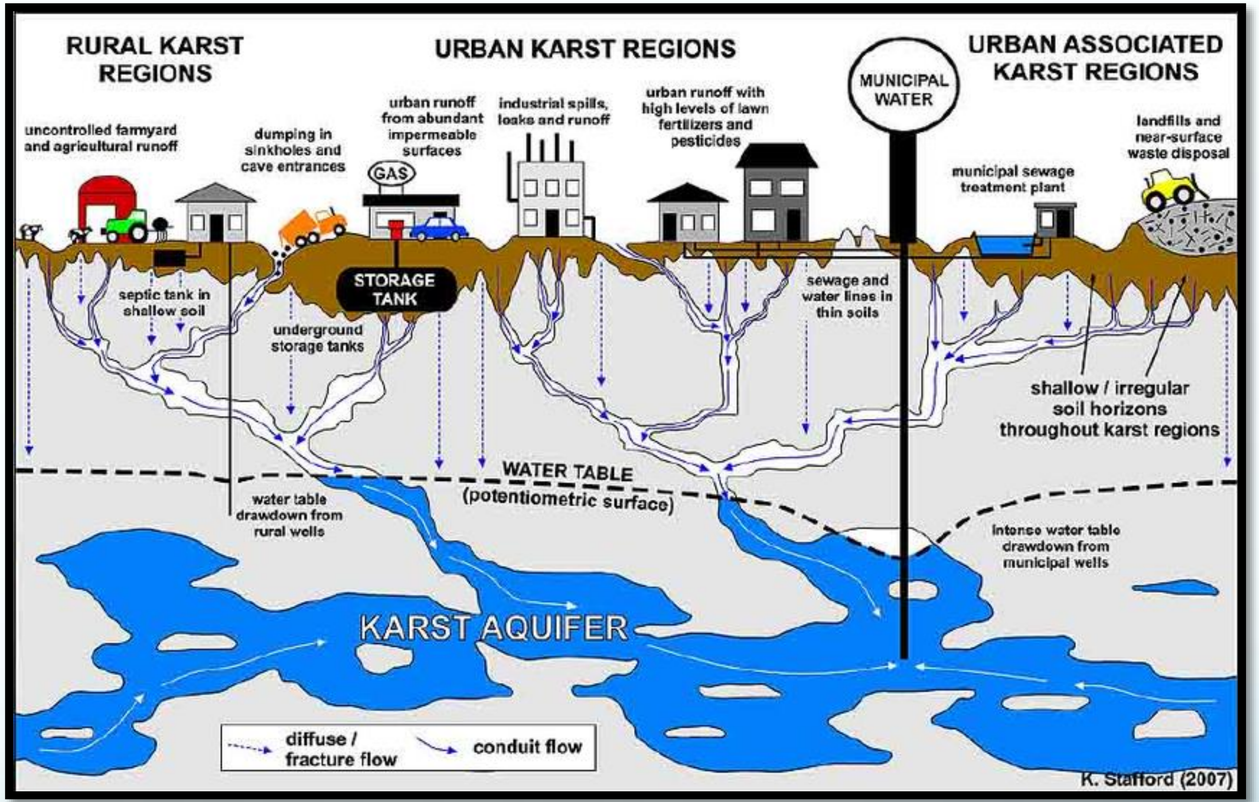
Methods: Evaluation, Verification, and Recommendations for the Framework

Testing and Validation of the Framework

- Manipulation of developed data set
  - Different resolutions and parameters applied to the framework
- Validation of the Framework and Assessment tool
  - Application of tools in the Tampa Bay Metropolitan Area
- Recommend modifications
  - Potential for development of management plan

Expected Results

- Create a data-driven urban karst groundwater monitoring framework that can be used universally
- Provide a framework that will explain what needs to be monitored and at what resolution
- Collect data that can then be used to support the development of management plans and drive groundwater protection through policymaking



Margane and Steinel (2011)

Questions

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