



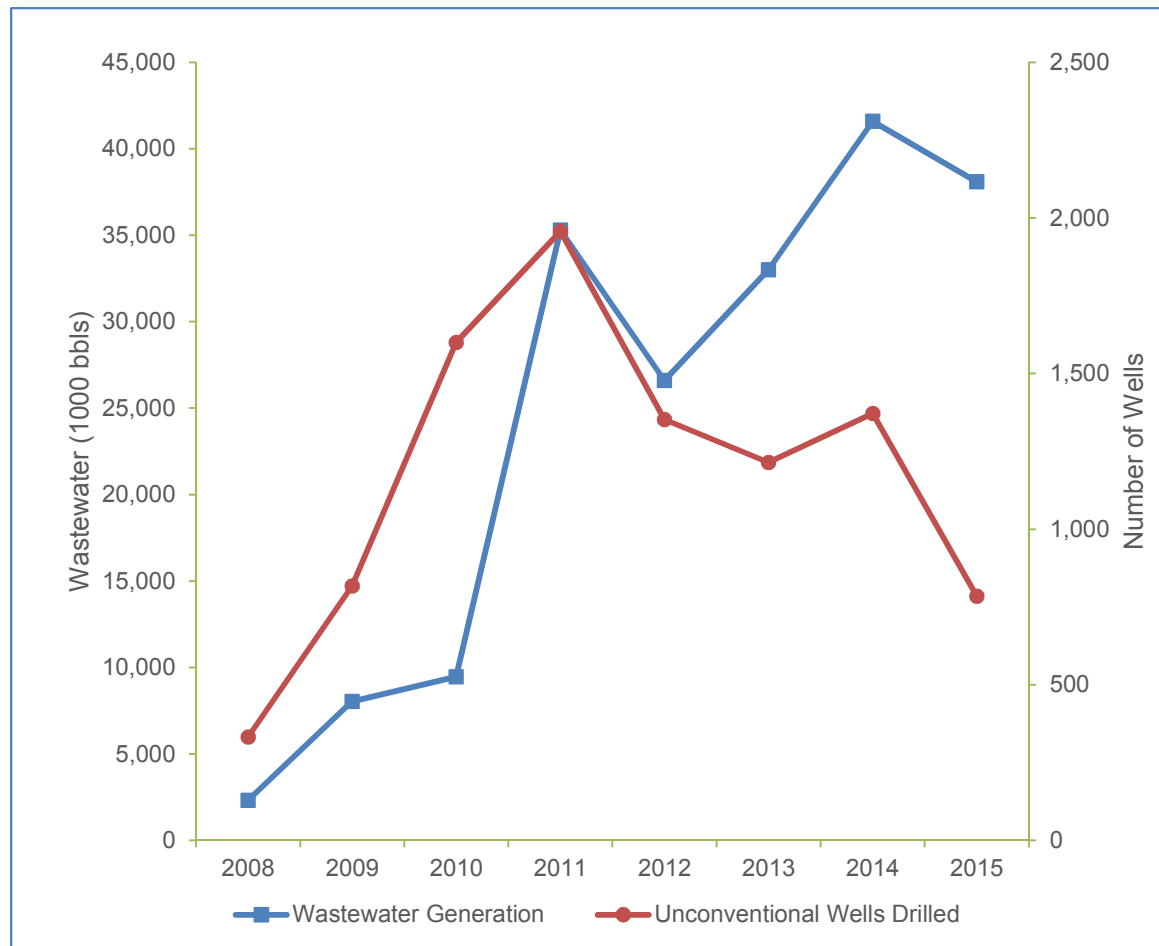
A Modeling Framework for Shale Gas Wastewater Management

Jhih-Shyang Shih, Elaine Swiedler, Alan Krupnick

Motivation

- Wastewater flows growing even as production falls

Well Drilled and Wastewater Generations in Pennsylvania

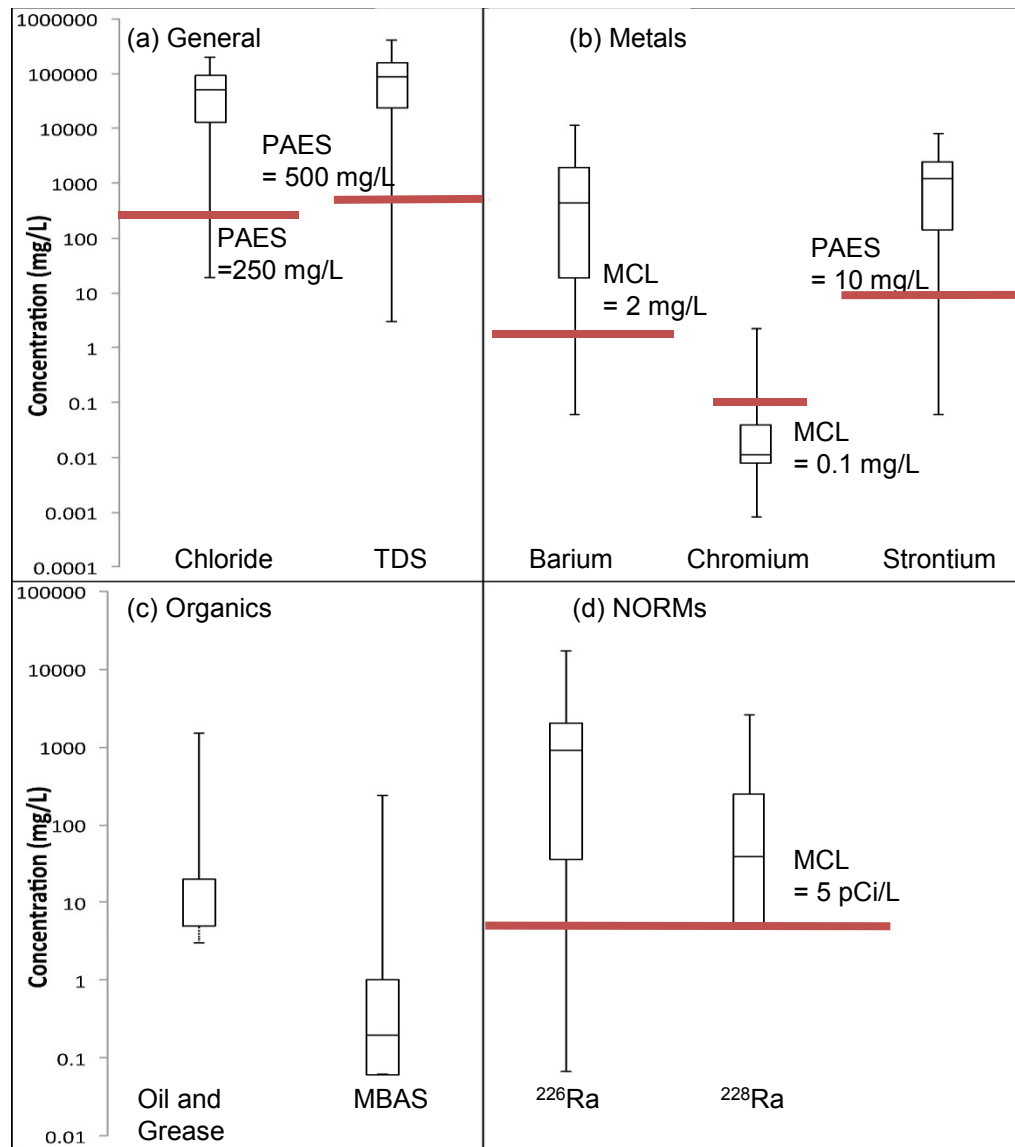


- New wells drilled has decreased since 2011
- Wastewater generation continues to increase
- EIA predicts shale gas production in PA will grow in the long run

Motivation

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- Nasty stuff (highly saline, NORMS, heavy metals)

Characteristics of Wastewater Quality

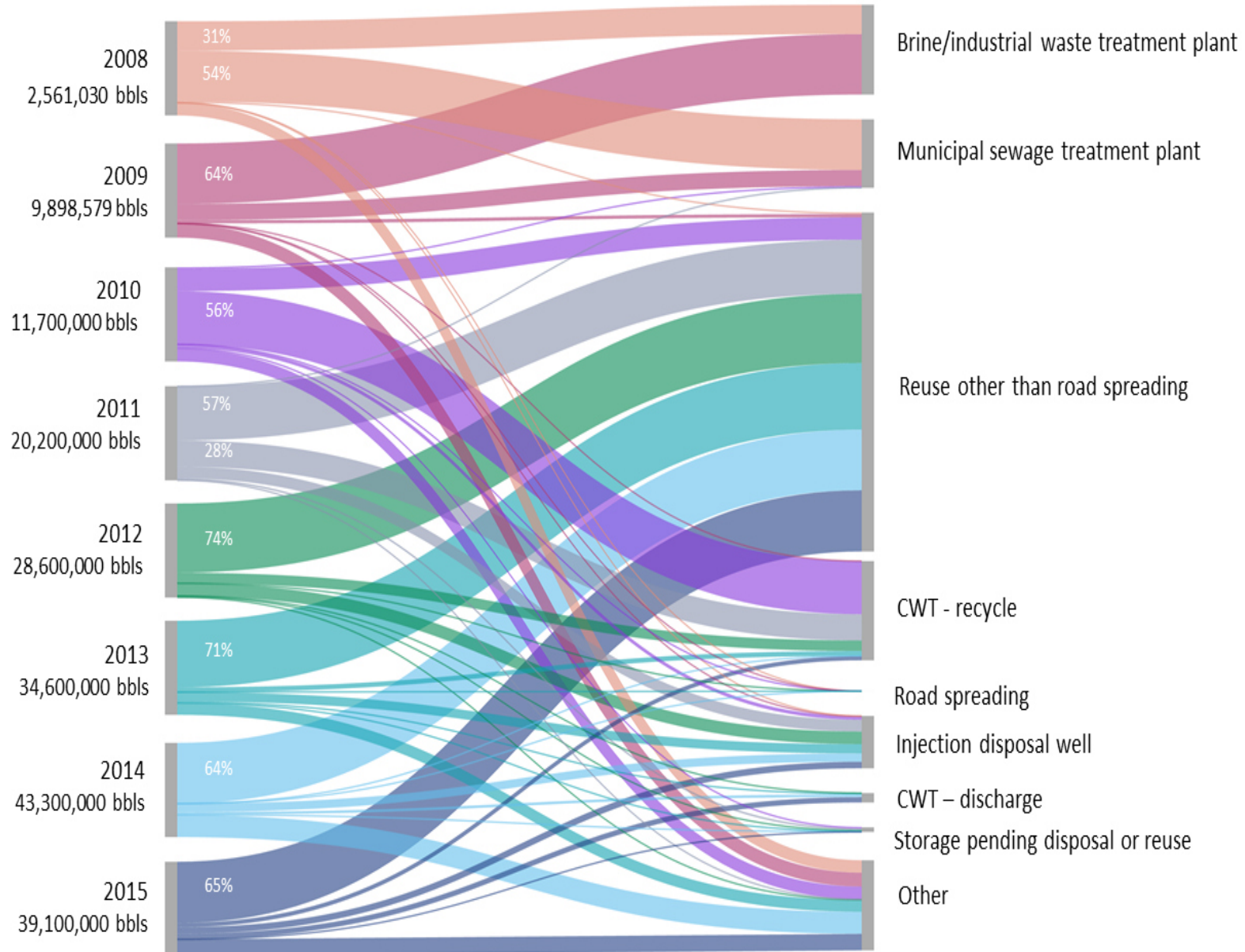


- Major constituents include salts, metals, organic toxics; and NORMs
- Wastewater in PA is very salty. In some cases, Cl concentrations are more than 10X sea water
- PADEP 2011 effluent standards for Cl and TDS are 250 mg/L and 500 mg/L

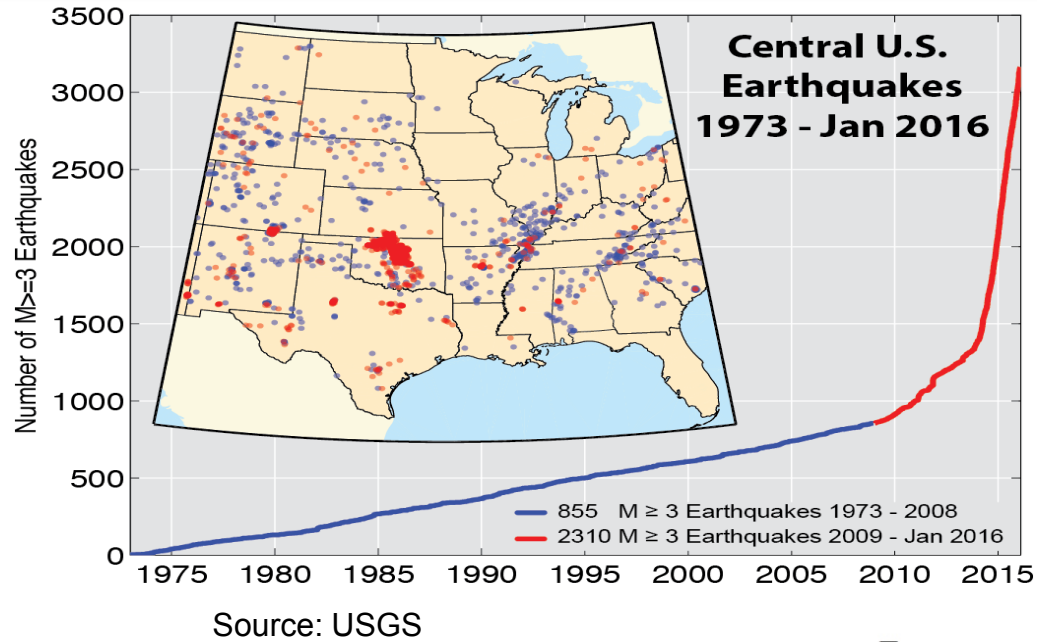
Motivation

- Wastewater flows growing even as production falls
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- Popular disposal pathways closed off or in jeopardy

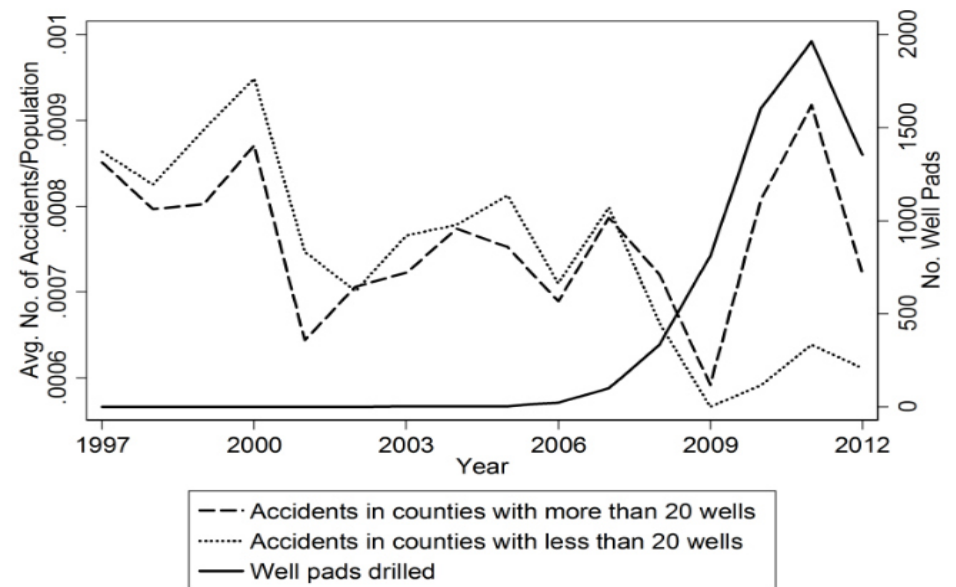
Evolution of Wastewater Management Options



Environmental Impacts



Source: Muehlenbachs and Krupnick (2013)



Motivation

- Wastewater flows growing even as production falls
- Nasty stuff (highly saline, NORMS, heavy metals)
- Popular disposal pathways closed off or in jeopardy
- Recycling for other uses underutilized
 - Regulations a problem

Why Wastewater Recycling and Reuse?

- Water scarcity (less of an issue in PA)
 - Reduce consumptive water use
 - Trucking costs
- Limited disposal options
 - Reduce wastewater generation
- Technologically feasible
 - Companies have developed treatment methods and to reuse saline wastewater for fracking without limiting production

Beneficial Uses of Recycled Water

- Produced water could be used to augment conventional water supplies for use in irrigation and livestock watering, stream flow augmentation, and industrial applications.
- Potential health risk to people and animals needs to be evaluated.
 - Elevated levels of sodium and other TDS, high conductivity, and radioactivity
- Liability and regulatory issues
- Need market development

Why We Need a Holistic System Approach

- Components are interconnected and complicated
- Multiple decision-makers
- Most research has focused on an individual component (i.e., a single treatment technology)
- Decision-makers need a tool for infrastructure investment planning and policy analysis

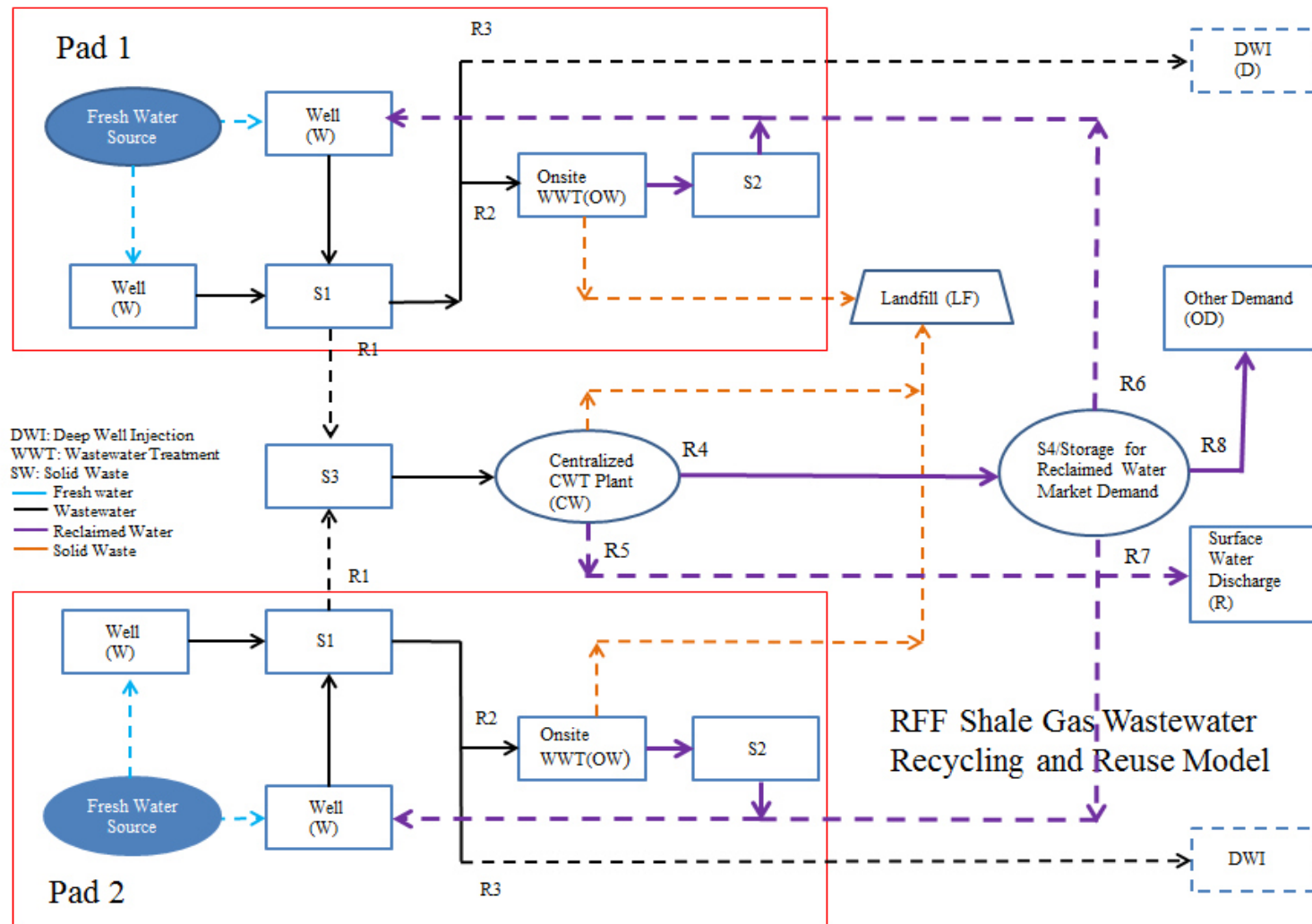
Objectives of the Research

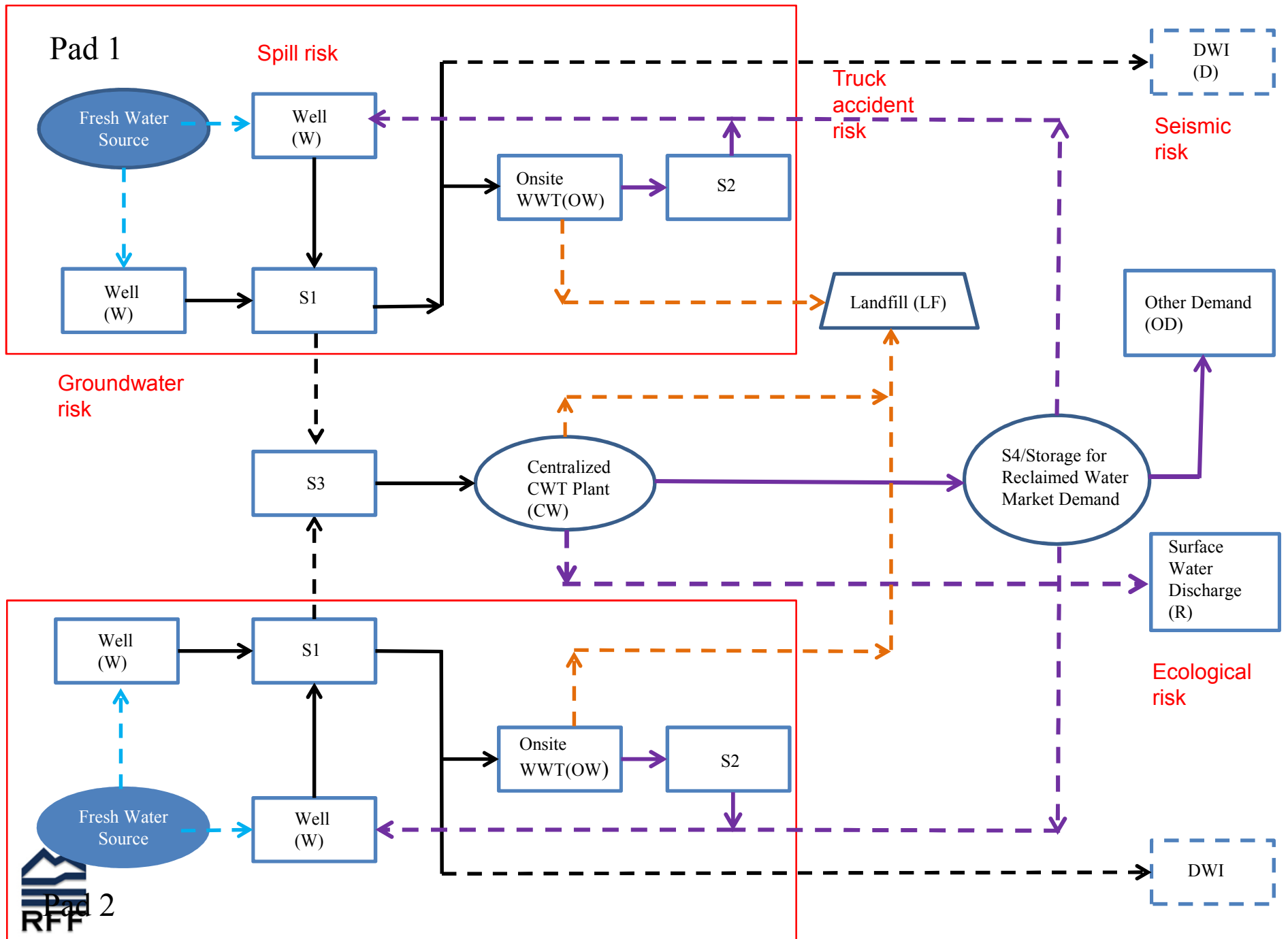
- Review literature on modeling decisions on how to dispose of produced water
- Develop a model
- Obtain a solution algorithm
- Parameterize the model
- Do a case study

Previous Wastewater Modeling Studies

- Yang et al. ([2015](#)) minimize costs from freshwater acquisition and wastewater handling (including impoundment, piping, treatment facilities and operation costs)
 - ➔ optimal impoundment capacity and location, pipe type, treatment facility locations and removal capacity, freshwater sourcing, and frack schedules.
- Gao and You ([2015](#)) maximize profit per unit of freshwater consumption
 - They include multiple transportation modes, management options, and treatment technologies.
 - Under their second case study: 95% of wastewater should be treated onsite and reused and 5% should be treated by CWT and discharged.

Model Development: System Domain





Key Features of the Model

- Maximize/Minimize an objective function subject to constraints
- Four objective functions
 - Operators: Minimize water acquisition and wastewater storage/treatment/transportation/disposal costs (includes associated solid wastes)
 - CWT facility owners: Maximize profits (including selling reclaimed water)
 - Regulators: Minimize environmental harms
 - Social planner: Minimize social costs (all the above)
- Decision variables: capacity (treatment and storage), allocations of wastewater to disposal options, choice of technical treatment options, blending ratio, transportation mode (pipeline vs. tank truck), wastewater shipment route (urban short distance vs. rural long distance), siting of treatment plants.
- Constraints: water balance, chemical balance, environmental standards, capacity constraints (e.g., landfill, DWI)

Conclusions and Future Work

- We developed a new, more comprehensive modeling framework for wastewater management.
- The multi-objective modeling framework is developed to incorporate the objectives of four different types of decisionmakers.
- The model is based on the current water life-cycle in Pennsylvania (Marcellus Shale) but could be adjusted for other shale plays.
- Future work includes refining the model, developing solution methods and strategies, collecting data, and conducting a case study and policy analysis.



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Onsite vs. Centralized Wastewater Treatment

	Advantage	Disadvantage
Onsite	<ul style="list-style-type: none">• No transportation cost• Low cost for primary treatment technology	<ul style="list-style-type: none">• Risk to fracking performance due to inadequate water quality• High cost for advanced treatment technology• Small treatment capacity and diseconomy of scale
Centralized	<ul style="list-style-type: none">• Flexible treatment technologies to meet water quality required for beneficial uses• Better account for wastewater audit• Meet higher effluent discharge standard	<ul style="list-style-type: none">• High transportation cost• High capital investment

Wastewater Treatment Technology

- Primary treatment
 - Clarification, filtration to remove TSS
 - Disinfection to remove bacteria
 - Fresh “make up” water is required to ensure adequate quality and quantity of fluid for fracking reuse
- Secondary treatment
 - Softening, coagulation, flocculation, filtration to remove TDS/salts and scaling compounds
 - Disinfection to remove bacteria
 - Fresh “make up” water is required to ensure adequate quality and quantity of fluid for fracking reuse
- Tertiary/advanced treatment for fracking reuse
 - Wastewater pre-treatment followed by desalination
 - Water will be treated to reach a pre-specified contaminant level and then well be blended with fresh make up water for fracking reuse
 - Tertiary treatment involves partial or complete desalination technologies.
- Tertiary/advanced treatment for discharge or beneficial use
 - The highest level of treatment
 - Under PADEP effluent standards, wastewater must be treated until TDS is below 500 mg/L

