Integrating WEPP and a pathogen transport model to simulate fate and transport of *Cryptosporidium parvum* and Rotavirus in surface flow

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Introduction

- Public health concerns for contamination of soil and water due to the presence of pathogens
- Over the past decade, a range of microbial pathogen outbreaks has stalked the globe
- Water-related diseases - the main cause of death in developing countries which accounts for 98% of the total death.
- About 3.5 million people (including 3 million children) die worldwide due to water related diseases every year. (Prüss-Üstün *et al., 2008)*
- In USA, 870 outbreaks were associated with drinking water during the period of 1920 to 2002 causing 883,806 illnesses. (Craun *et al.,* 2006)

Why *Cryptosporidium*?

- *Cryptosporidium* – a protozoa (4-6 micrometer in size) which is the most frequently-occuring biological contaminant in the United States. (Fayer *et al.,* 1997)
- About 25-35% of the population in developed countries (including the United States) has had cryptosporidiosis at some time in their lives. (Sureshbabu *et al., 2010)*
- About 300,000 cases of diarrhea annually resulting from cryptosporidiosis in the United States. (Mead *et al.,* 1999)
- About 403,000 people were infected from a massive outbreak of *Cryptosporidium parvum* at Milwaukee in 1993 with more than 100 fatalities, the largest waterborne disease outbreak in USA. (MacKenzie *et al.,* 1994)
- Reason: Common treatment provided for drinking water (Chlorine disinfection) could not kill *Cryptosporidium.*

Why Rotavirus?

- Rotavirus – a virus (65-75 nanometer in size) which is the most frequently detected pathogen in children under two years of age in developing countries.
- Rotavirus has a large range of hosts: humans, calves, pigs, lambs, foals, rabbits and deer, making it a wide-spread infectious agent.
- More than 500,000 deaths annually in young children primarily in developing countries due to rotavirus infections. (Bishop*,*1996)
- Rotavirus causes approximately 111 million episodes of gastroenteritis requiring only home care, 25 million clinic visits and 2 million hospitalizations each year around the globe. (Parashar *et al.*, 2003*)*
- WHO has recommended two live oral rotavirus vaccines (RotaTeq and Rotarix) for inclusion into the national immunization programs worldwide in 2009.

Why pathogen transport modeling?

- Modeling can help understanding pathogen transport pathways. Accordingly, best management practices (BMP) can be developed.

- Although the prediction of fate and transport of pathogens has the great practical importance, the mathematical modeling of the phenomenon has been illustrated in few literatures only.

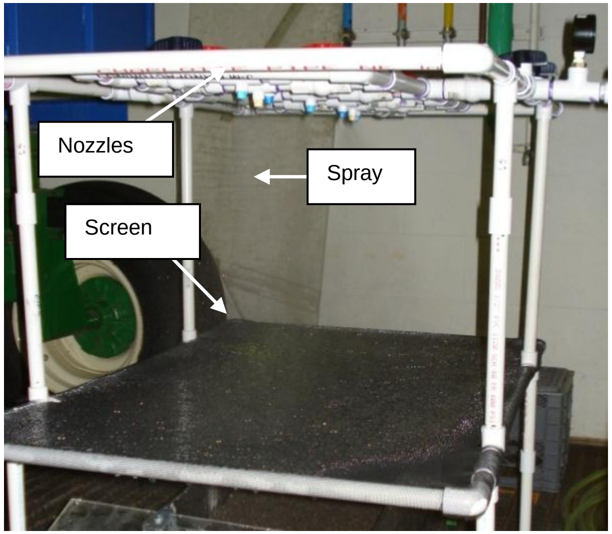
Objectives

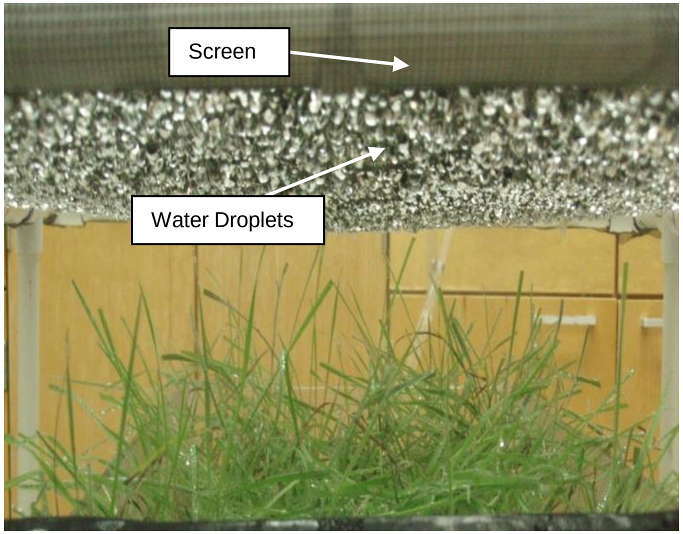
- Develop a physically-based predictive model for pathogen (*Cryptosporidium parvum* and Rotavirus) transport in overland flow

- Calibrate and validate the model using observed data

- Analyze the observed and predicted results and develop recommendation on further use of the model for designing BMP (such as VFS) to control microbial pathogen transport

Experimental set-up





Experimental setup

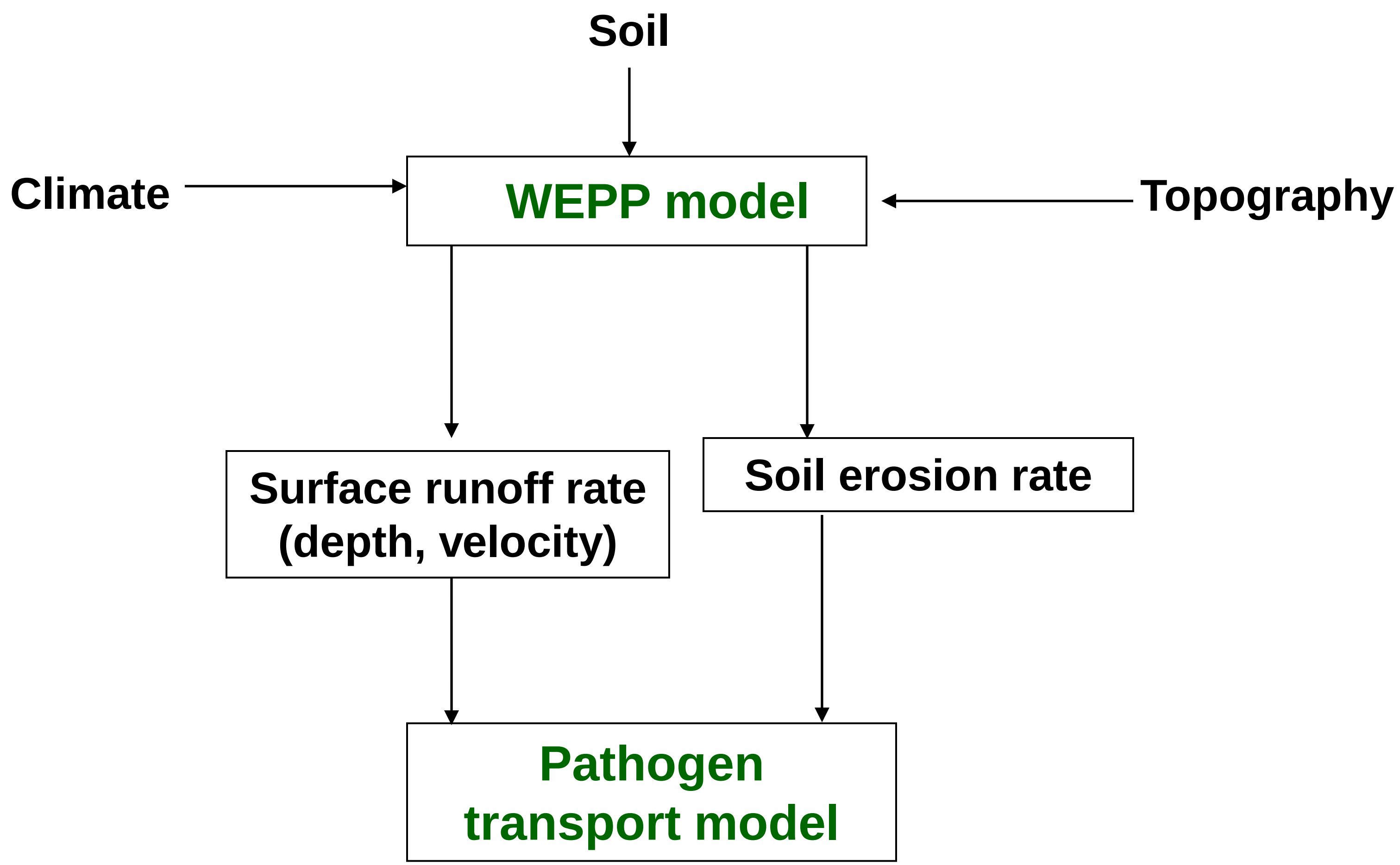
- 65 mm/hr (2.5 in/hr) rainfall intensity applied for 20 mins
- Catlin silt-loam, Alvin fine sandy-loam, Darwin silty-clay soils
- Soil bed dimension: 0.67 m x 0.33 m x 0.076 m
- 2.5% bed slope
- Bare and vegetated (Brome and Fescue) cover conditions

Experimental results

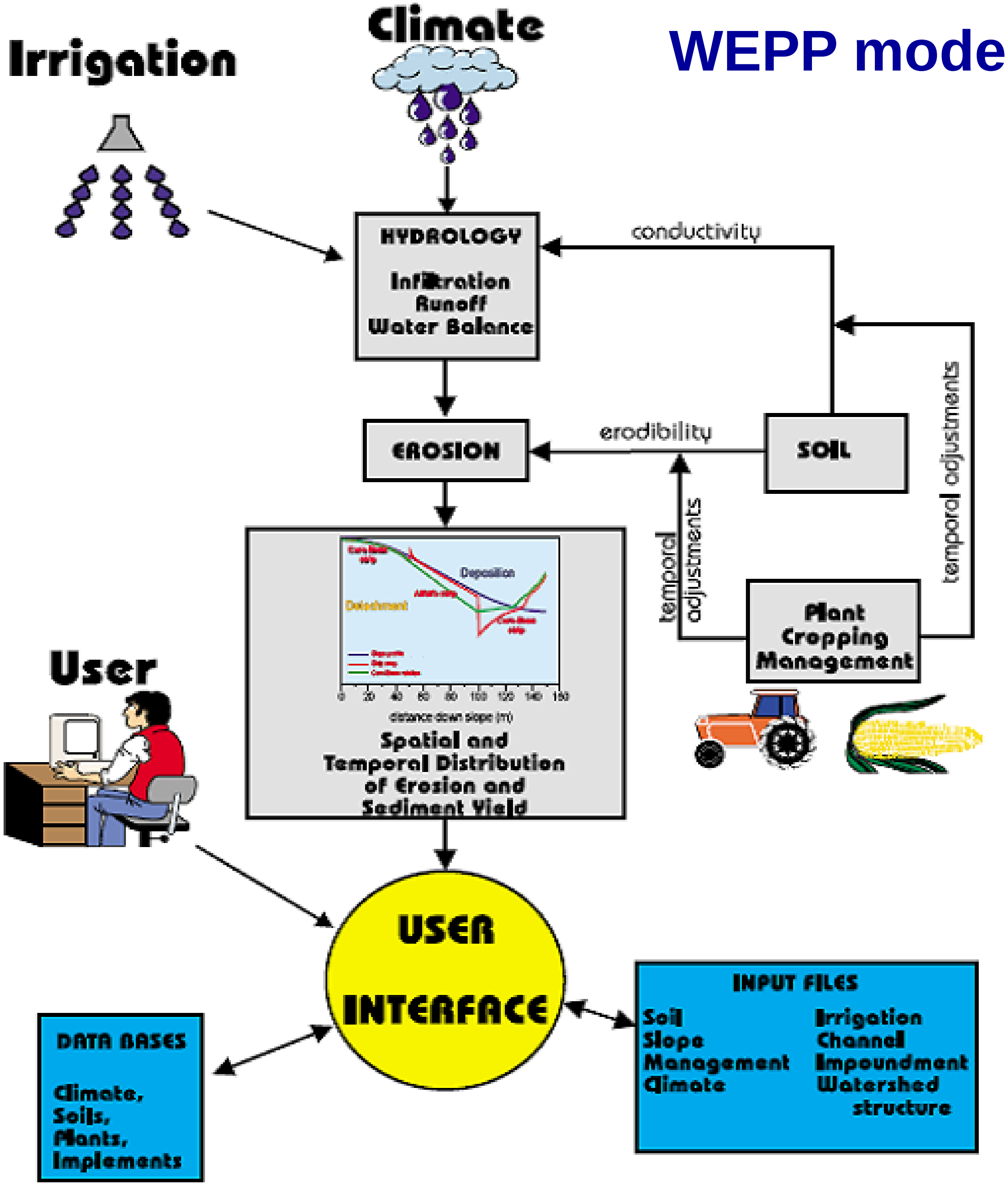
Surface Condition	Soil type	Total Runoff (mL)	*C. parvum* recovery (%)	Rotavirus recovery (%)
Bare	Catlin	4384.0	33.38	34.92
Vegetated (Brome)	Catlin	2387.0	14.91	9.87
Vegetated (Fescue)	Catlin	284.0	22.07	14.23
Bare	Darwin	3189.0	38.58	26.56
Vegetated (Brome)	Darwin	2711.0	8.81	16.91
Vegetated (Fescue)	Darwin	467.0	0.00	0.08
Bare	Alvin	3140.0	1.17	8.28
Vegetated (Brome)	Alvin	2139.0	1.10	0.67
Vegetated (Fescue)	Alvin	1301.0	0.06	1.83

- Most probable number (MPN) method for *C. parvum* enumeration
- Focus forming unit (FFU) method for Rotavirus enumeration

Model overview



WEPP model overview



Flow chart for the WEPP erosion prediction model system.

Pathogen transport modeling

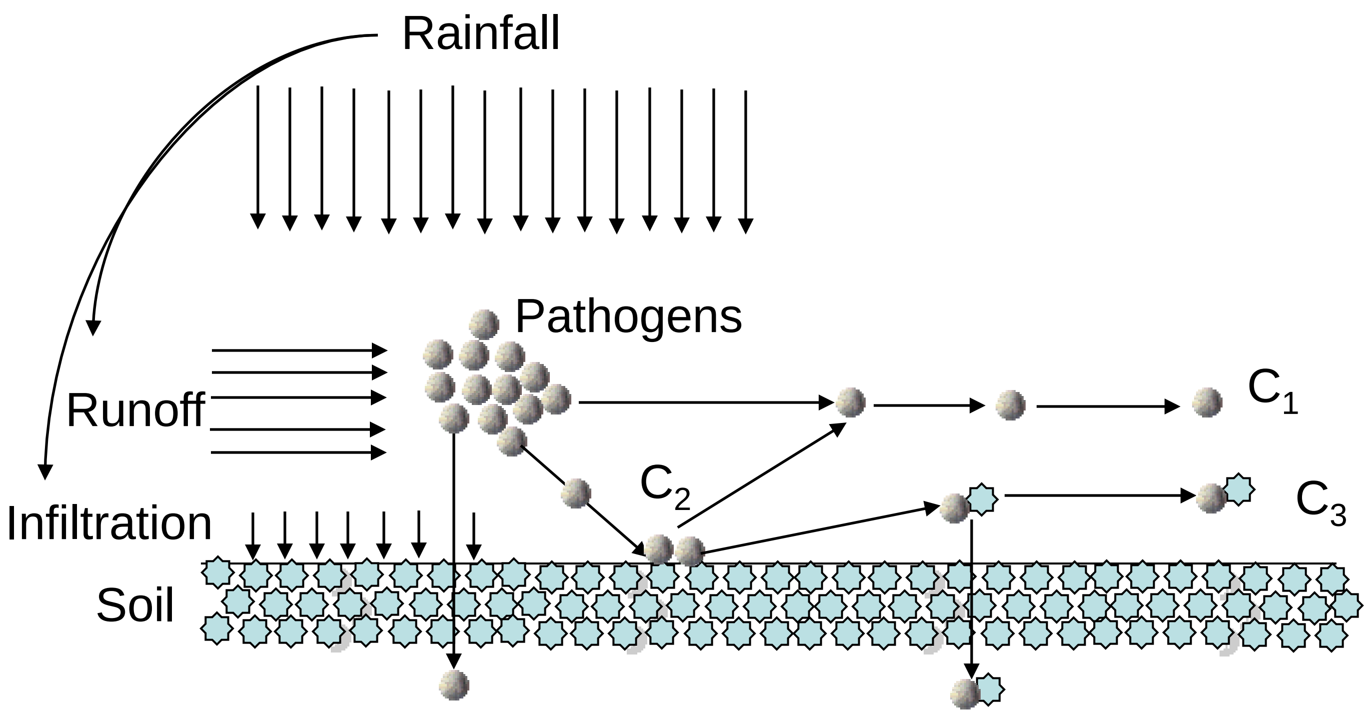
The following possible states of pathogen fate and transport are considered in overland flow:

(1) Pathogens attach to soil particles with attachment rate k_{12}

(2) Pathogens attached to soil particles are removed by surface flow with rate constant k_{21} and k_{23}

(3) Pathogens become inactivated with inactivation rate k_d

(4) Pathogens are removed by infiltration with the rate equal to *f/D (f* is hydraulic conductivity, and *D* is flow depth)



Pathogen transport modeling

Concentrations of pathogens in water (C_1), attached to immobile soil particles (C_2), attached to mobile soil particles (C_3) can be calculated using the set of following mass balance equations:

$$\frac{\partial C_1}{\partial t} + u\frac{\partial C_1}{\partial x} = -(k_{12} + k_d + \frac{f}{D})C_1 + k_{21}C_1$$

$$\frac{\partial C_2}{\partial t} = k_{12}C_1 - k_{21}C_2 - k_{23}C_2$$

$$\frac{\partial C_3}{\partial t} + u\frac{\partial C_3}{\partial x} = k_{23}C_2 - (k_d + \frac{f}{D})C_3$$

Initial condition: the pathogens are unattached and freely moving in the water at time zero

Boundary condition: there is no continuous source of pathogens exists at x = 0

Pathogen transport modeling

In case of vegetation cover condition, the system of equations becomes:

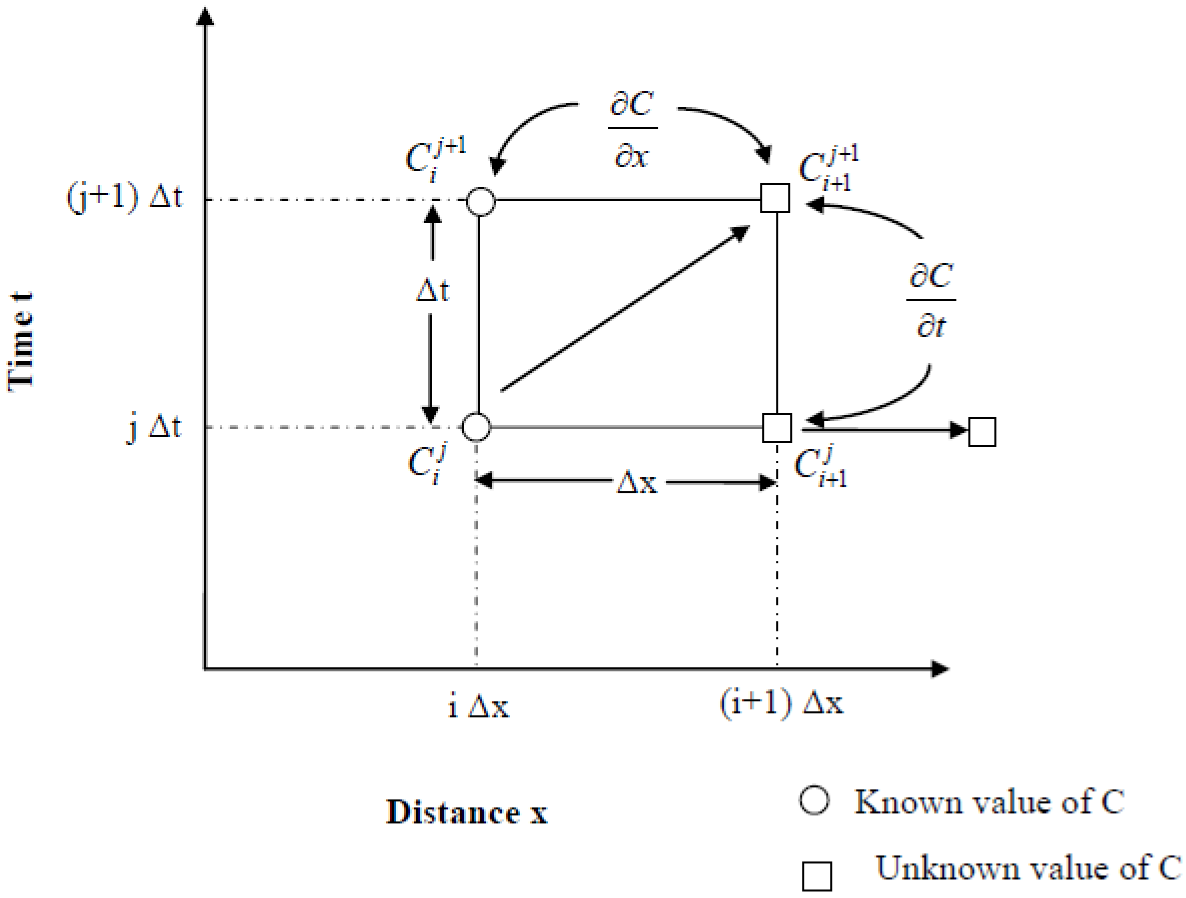
$$\frac{\partial C_1}{\partial t} + u\frac{\partial C_1}{\partial x} = -(k_{12} + k_{14} + k_d + \frac{f}{D})C_1 + k_{21}C_2 + k_{41}C_4$$

$$\frac{\partial C_2}{\partial t} = k_{12}C_1 - (k_{23} + k_{21})C_2$$

$$\frac{\partial C_3}{\partial t} + u\frac{\partial C_3}{\partial x} = k_{23}C_2 - (k_d + \frac{f}{D})C_3$$

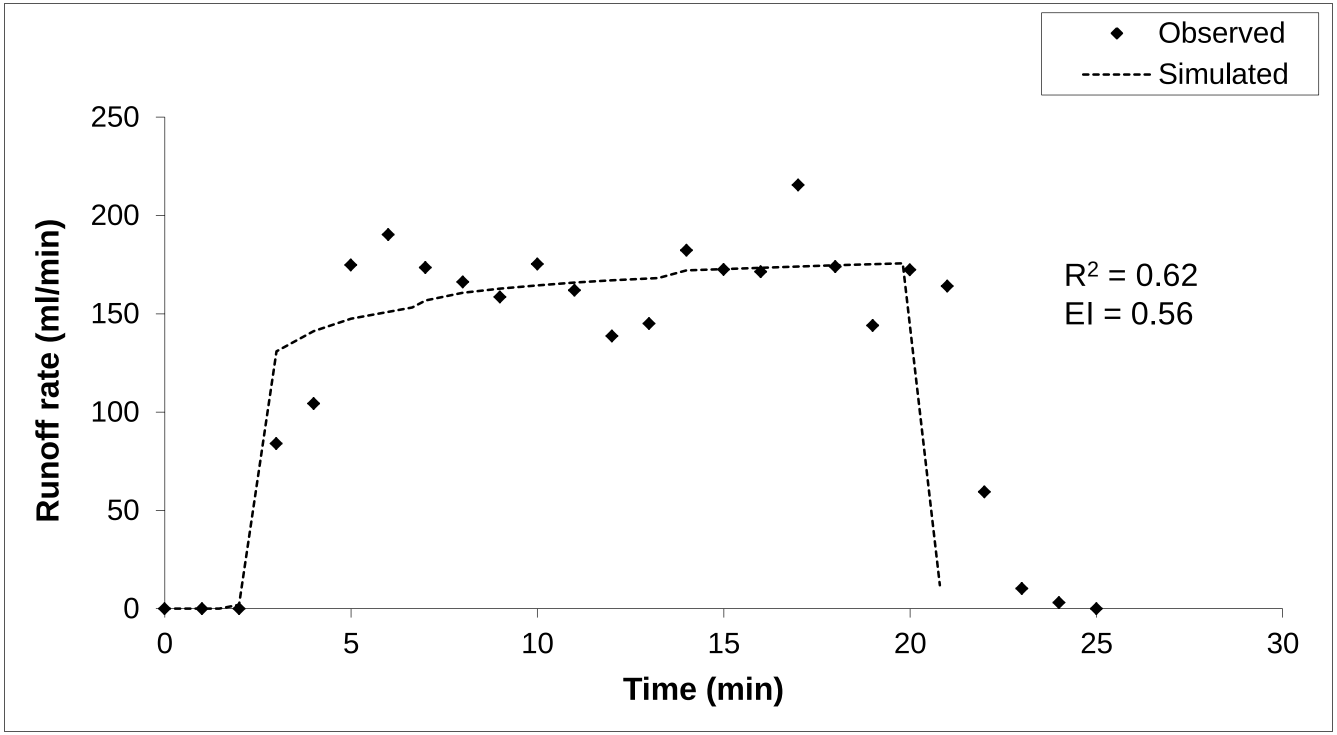
$$\frac{\partial C_4}{\partial t} = k_{14}C_1 - k_{41}C_4$$

Pathogen transport modeling



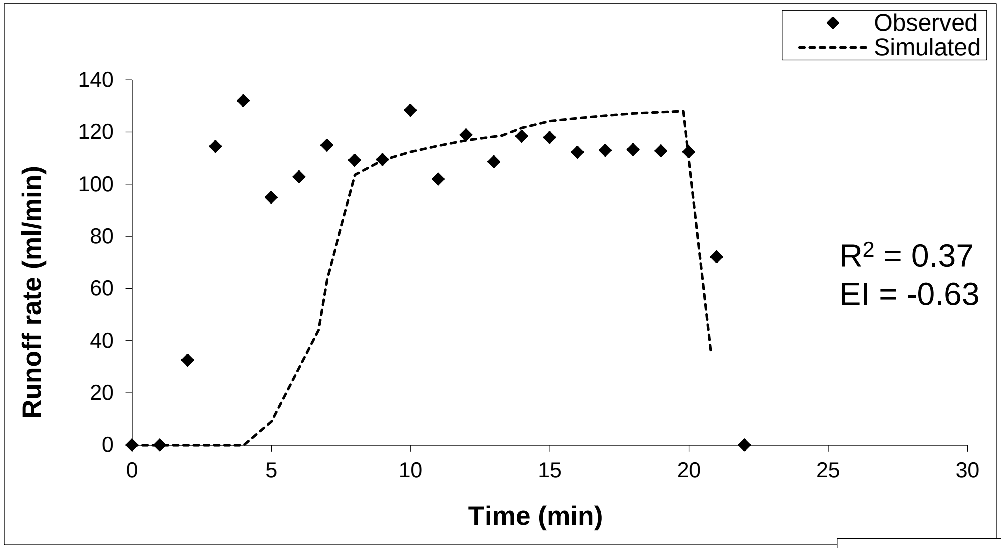
- Solved using the method of characteristics

Calibration of WEPP model for surface runoff

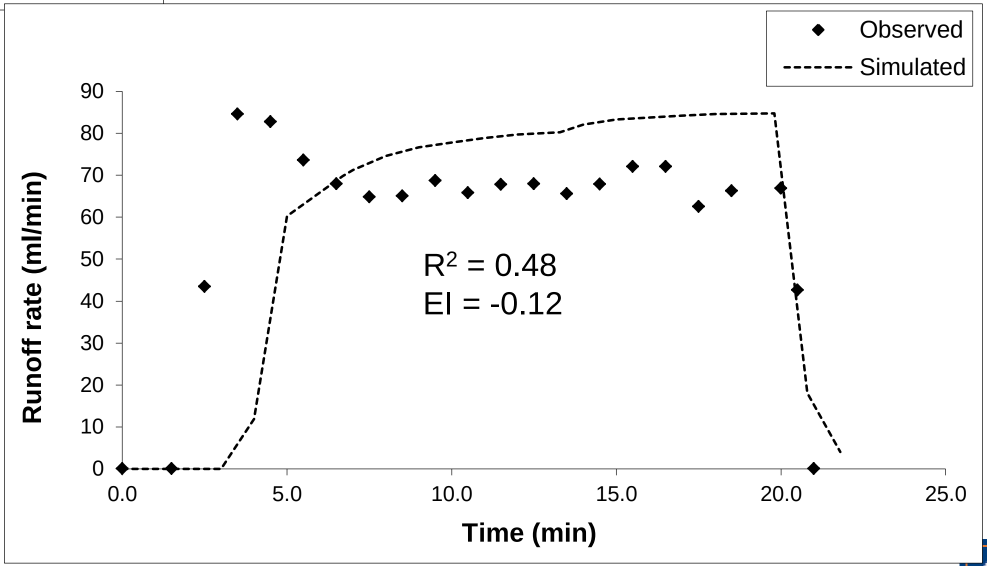


Rainfall intensity - 2.5 inch/hr, slope – 2.5% for bare Alvin soil

Calibration of WEPP model for surface runoff

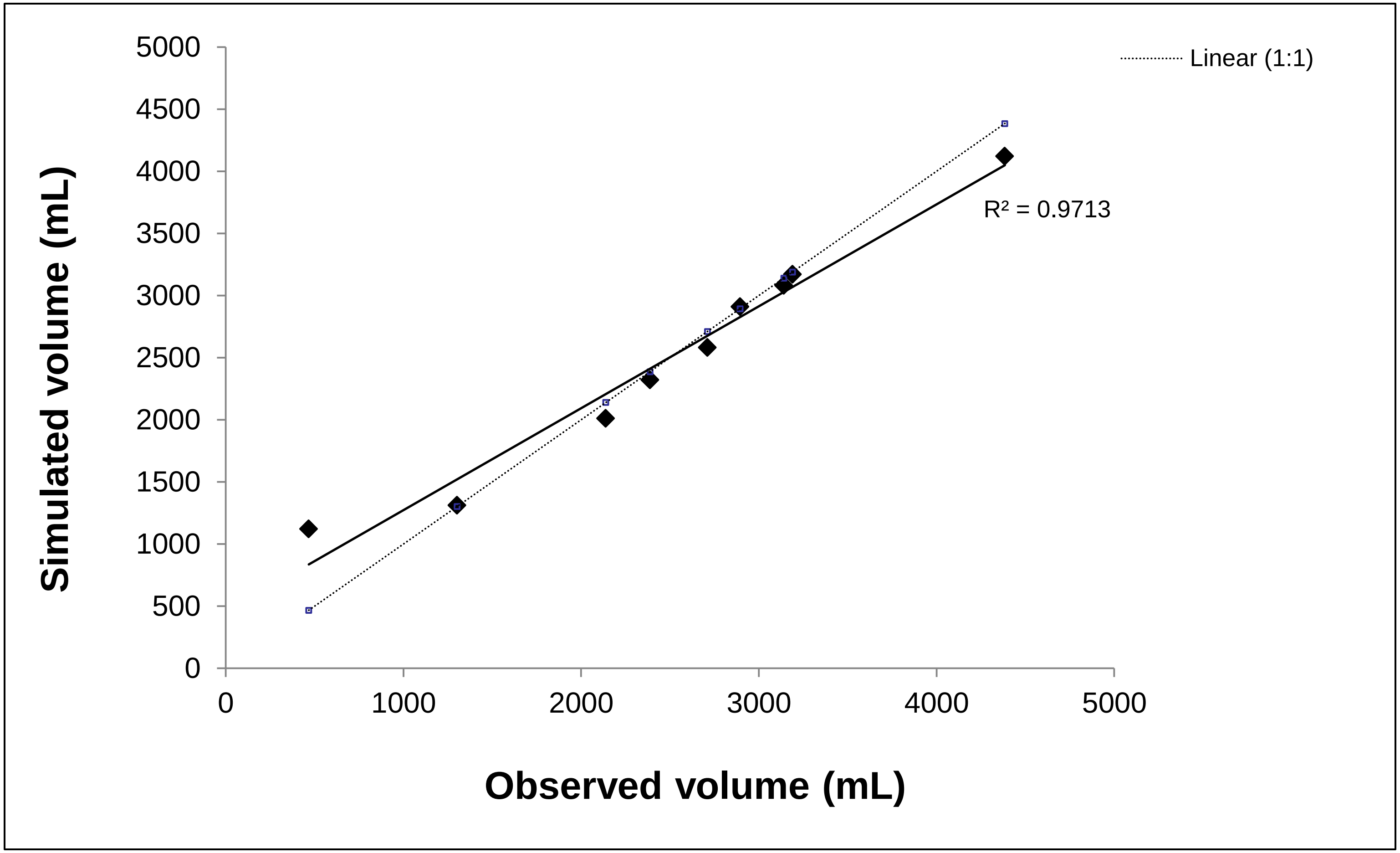


Alvin soil bed with Brome grass cover



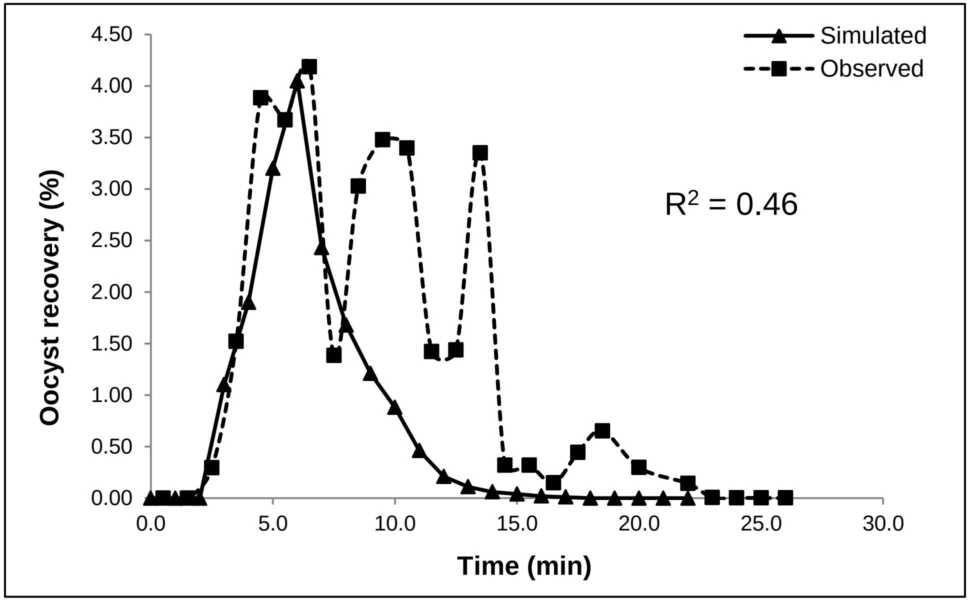
Alvin soil bed with Fescue grass cover

Calibration of WEPP model for surface runoff

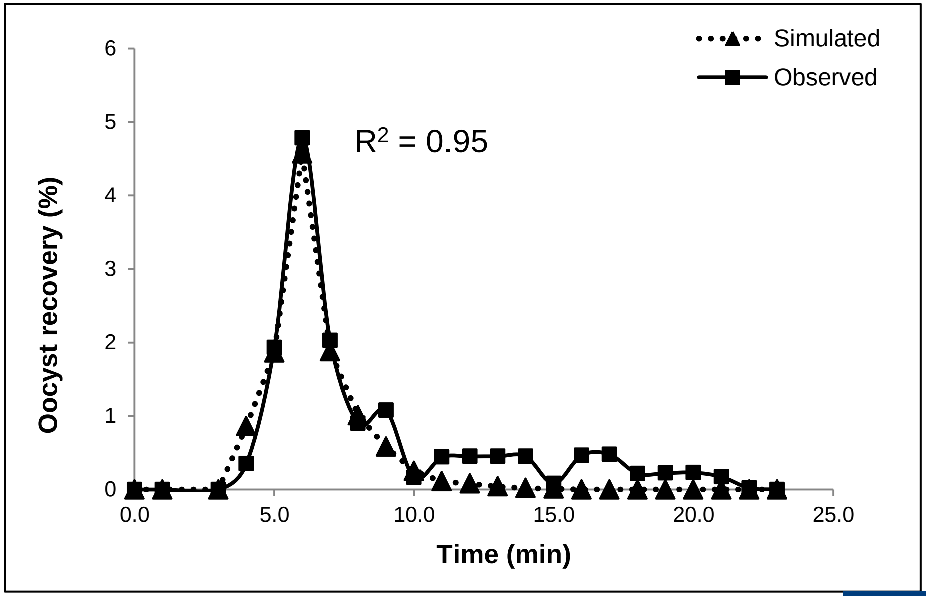


Comparison of observed and simulated runoff volumes

C. parvum transport model results

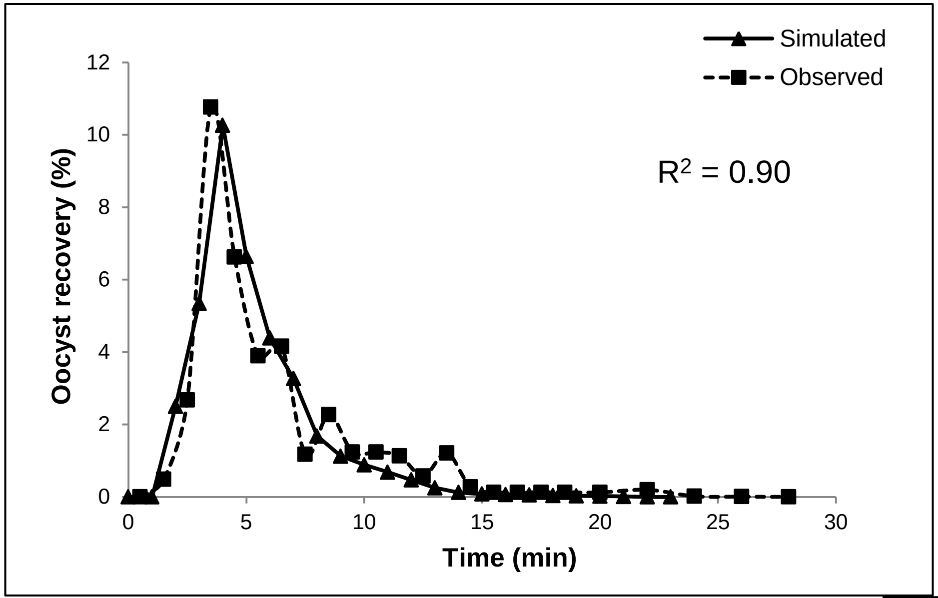


Catlin soil with no cover

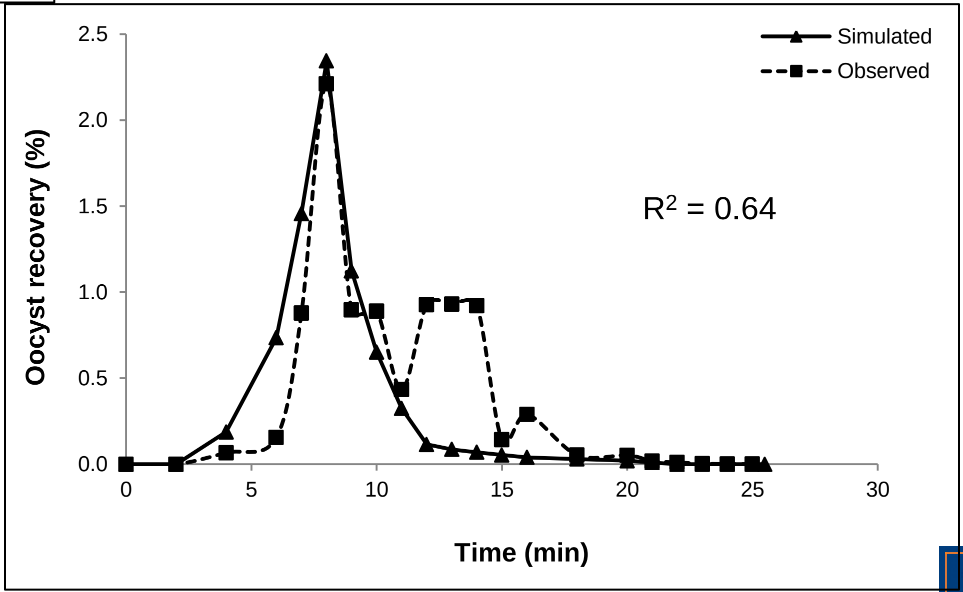


Catlin soil with Brome grass cover

C. parvum transport model results

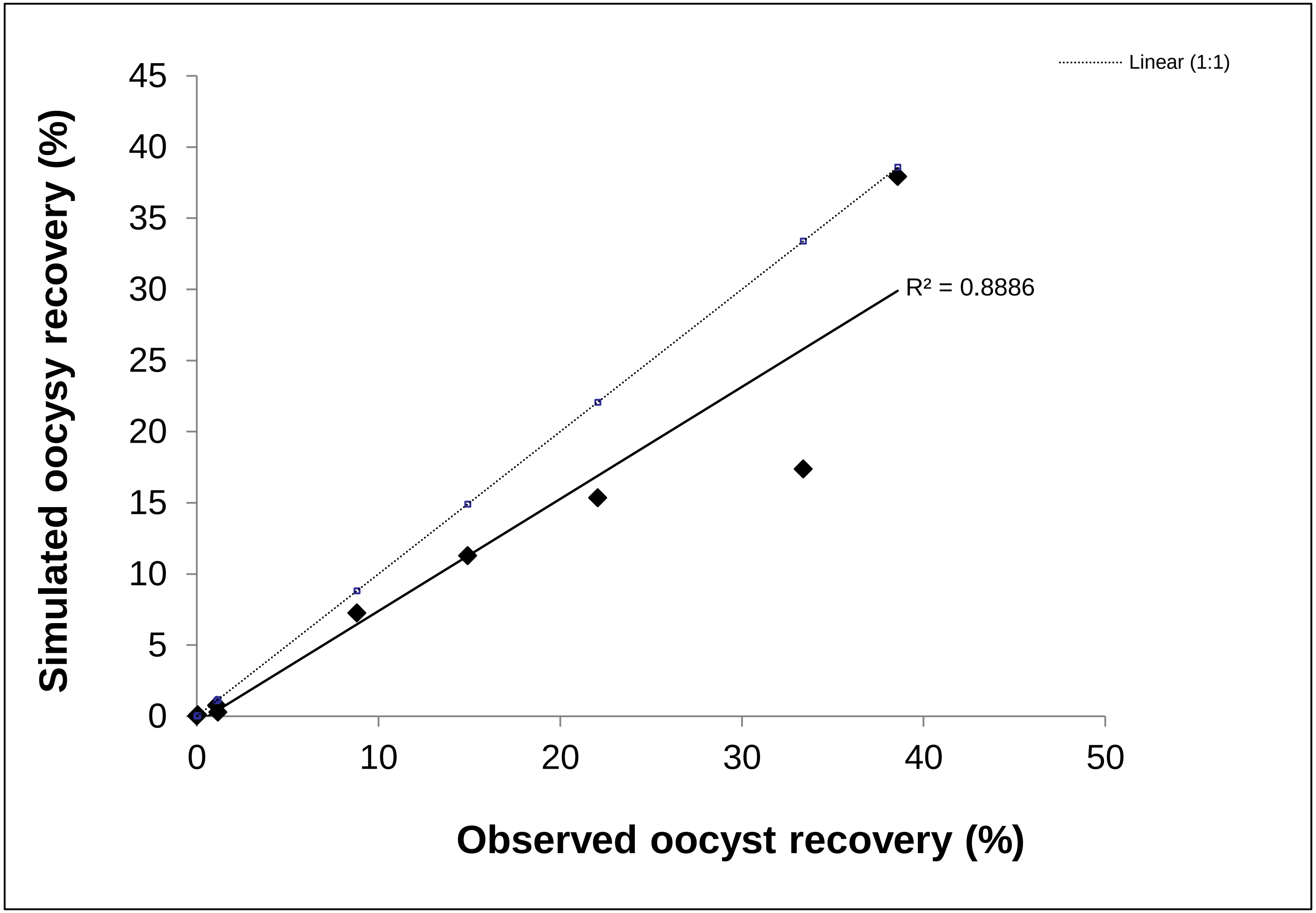


Darwin soil with no cover



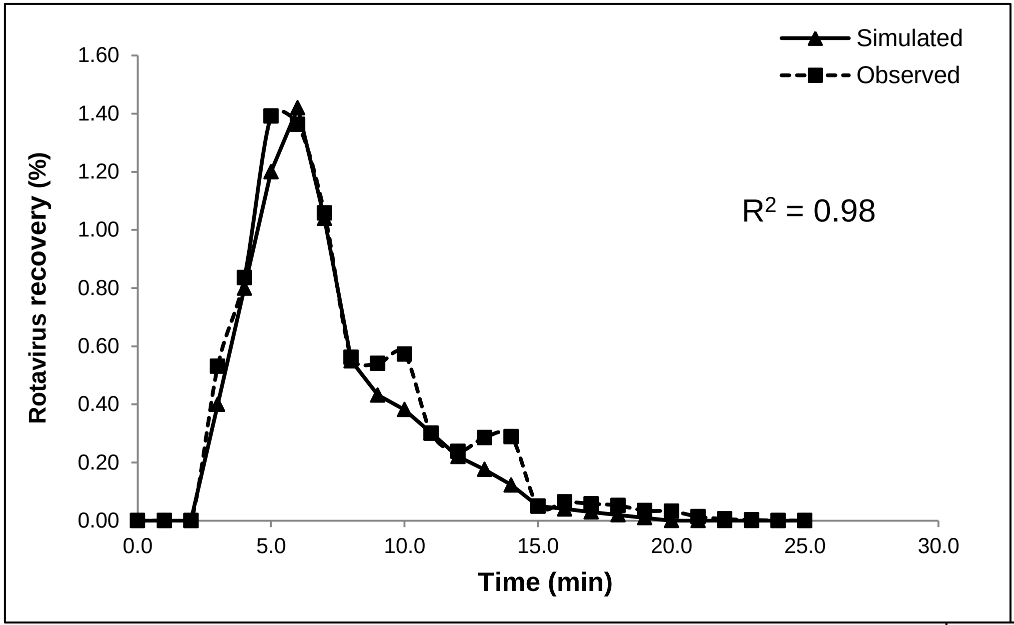
Darwin soil with Brome grass cover

C. parvum transport model results

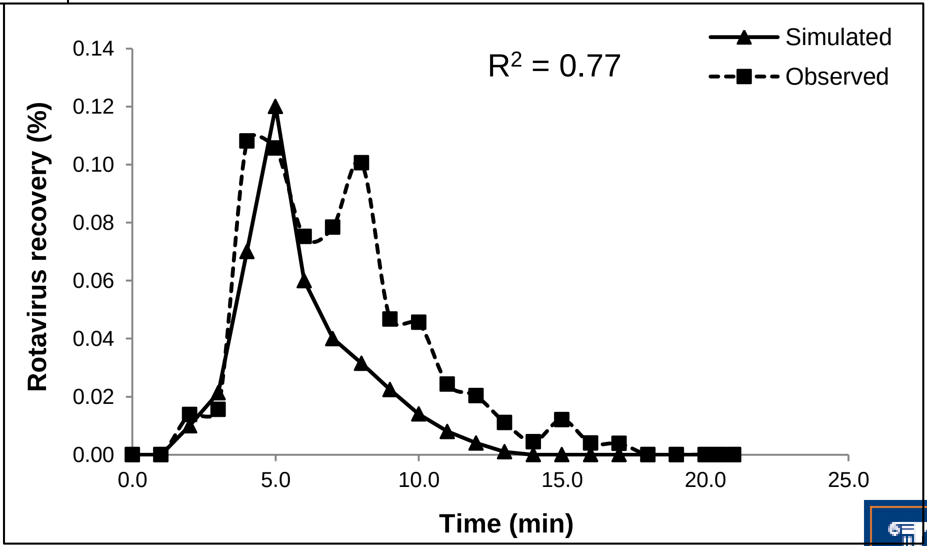


Bare and Vegetated (Brome and Fescue) Alvin, Catlin and Darwin soil

Rotavirus transport model results

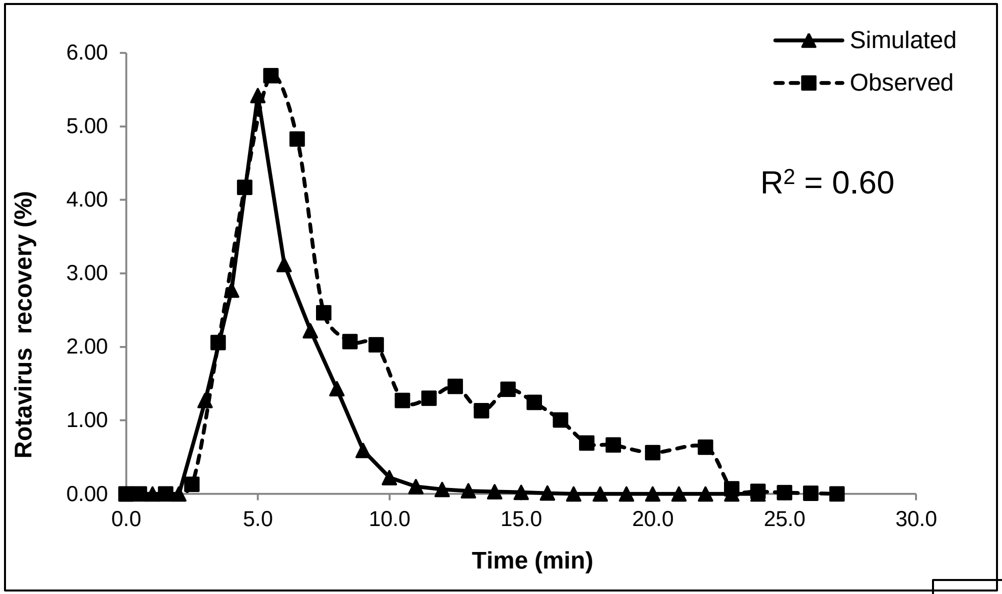


Alvin soil with no cover

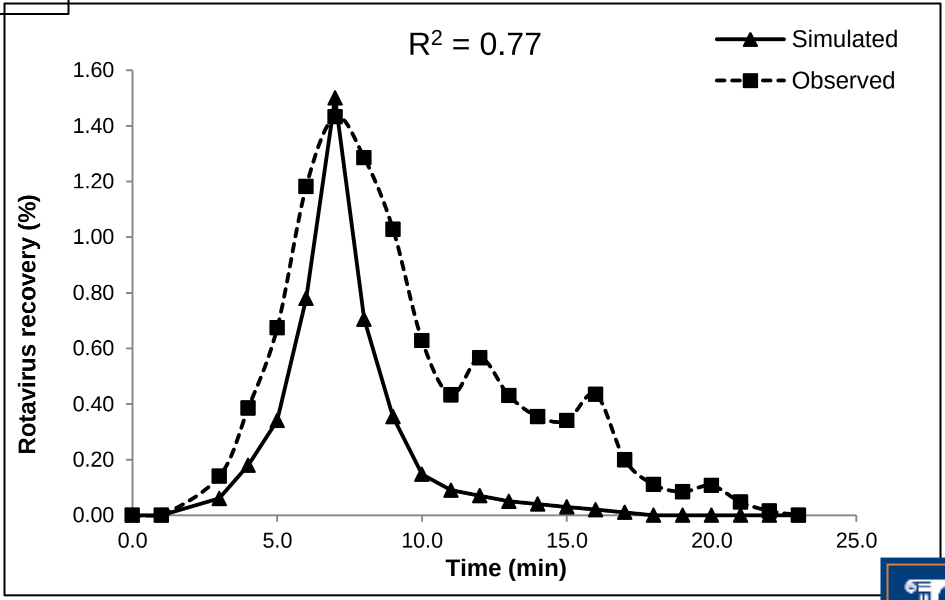


Alvin soil with Brome grass cover

Rotavirus transport model results

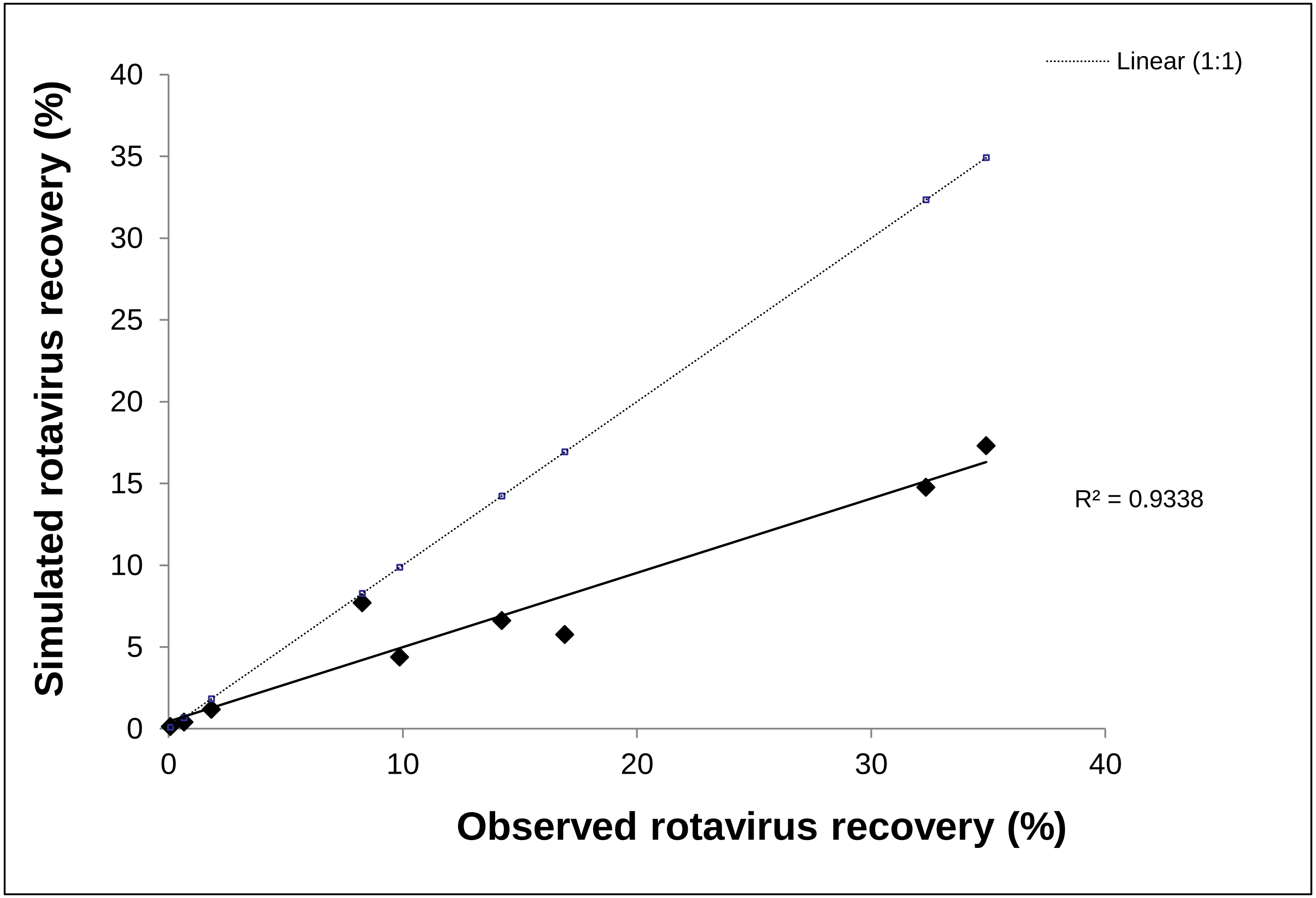


Catlin soil with no cover



Catlin soil with Brome grass cover

Rotavirus transport model results



Bare and Vegetated Alvin, Catlin and Darwin soil

Conclusions

- A physically-based approach for modeling microbial pathogen transport model for C. parvum and rotavirus fate and transport in surface flow has been developed and presented in this study.
- A feature of the model is the incorporation of an erosion model (WEPP) into the microorganism transport model, thereby establishing a link between the sediment and microbial transport.
- The model results showed good agreements with observed data in most cases. In few cases, experimental data showed multiple peaks in pathogen break-through curve, however this phenomenon could not be simulated by the modeling framework.
- The multiple peaks observed in experimental data can be attributed to different factors: clogging of the outflow system temporarily due to sediment, pathogen interaction with soil and vegetation, pathogens entrapment by sediments, etc.
- With further verification of the model results under various experimental conditions, the model can be used for designing BMP (such as VFS) to control microbial pathogen transport into water resources.

Thank you !!

Questions??