A practical introduction to modeling complex systems. A primer for thinking about the introduction and spread of infectious diseases along the farm-to-fork continuum.

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CHANGING LIVES
IMPROVING LIFE

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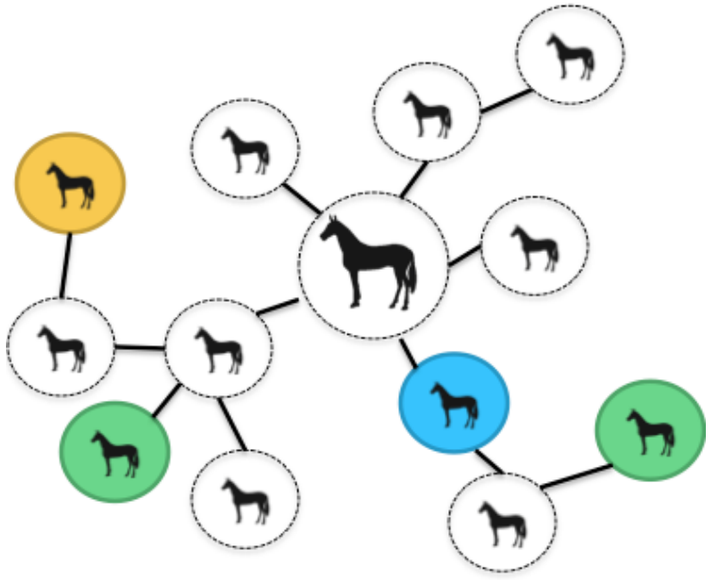
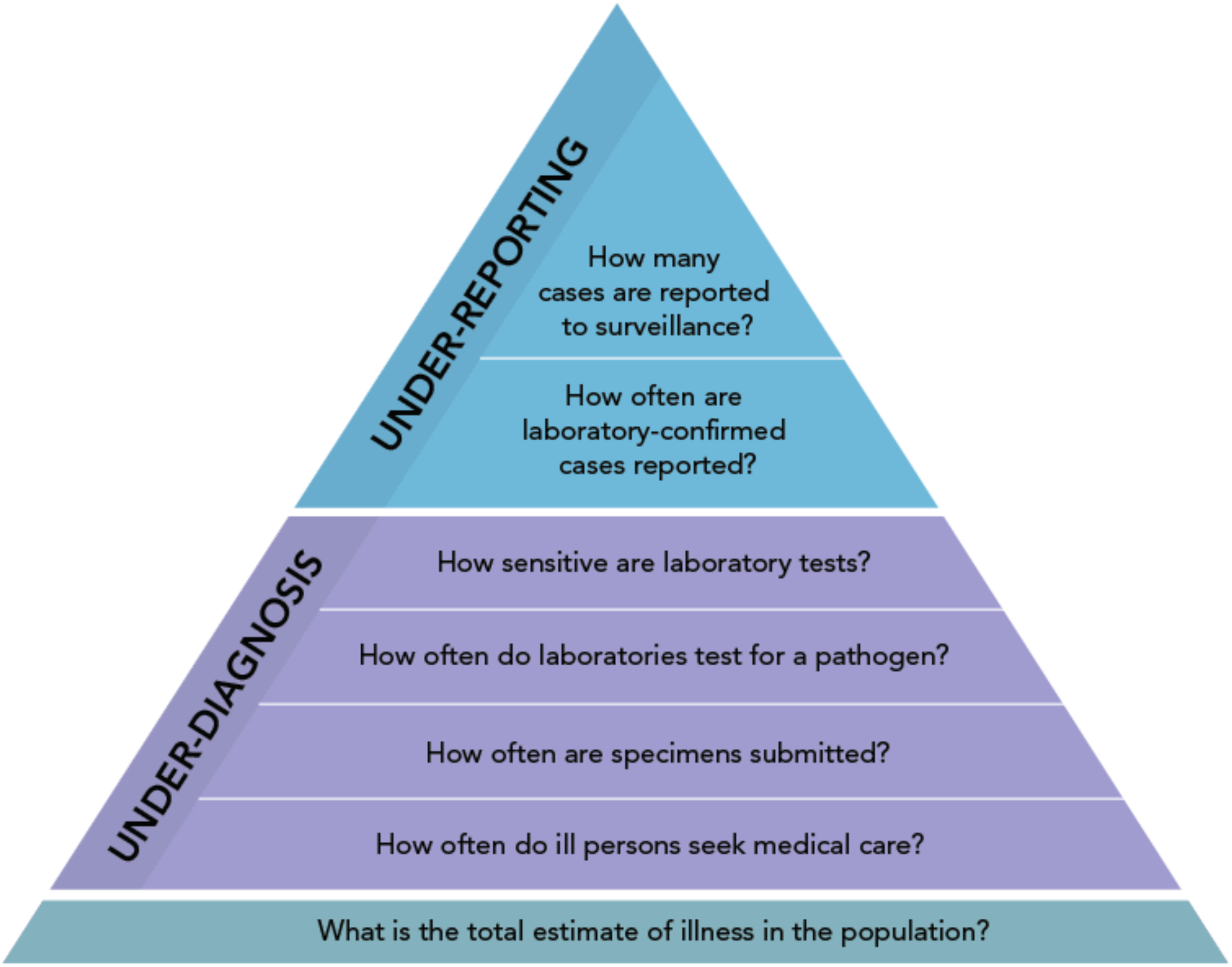


www.mathepilab.org

Outline

- Food-borne disease risk in Canada as a “One Health” case study.
- Using statistical models to identify acute environmental effects.
- Pre-harvest interventions to prevent and control the spread of food-borne pathogens in animal products and produce.
- The challenging health economics of pre-harvest interventions.
- Conclusions and ideas for moving forward.

Figure 1 Burden of illness pyramid



Thomas et al. 2013

Table 1. Estimated annual number of domestically acquired food-borne illnesses due to 30 known pathogens and unspecified agents transmitted through food in Canada, circa 2006 [1]

Food-borne agents	Estimated annual number of illnesses (90% credible interval)	%
30 known pathogens	1.6 million (1.2–2.0 million)	40
Unspecified agents	2.4 million (1.8–3.0 million)	60
Total	4.0 million (3.1–5.0 million)	100

1 The data used were based on the 2000-2010 time period, and the 2006 Canadian Census was used as a referent population thus the estimates are based circa the year 2006.

Table 2. Top four pathogens causing domestically acquired food-borne illnesses in Canada, circa 2006

Pathogen	Estimated annual number of illnesses (90% credible interval)	%
Norovirus	1,047,733 (679,576 – 1,434,048)	65
Clostridium perfringens	176, 963 (95,225 – 270,160)	11
Campylobacter spp.	145,350 (95,686 – 212,971)	8
Salmonella, nontyphoidal	87,510 (58,832 – 125,525)	5
Subtotal		89

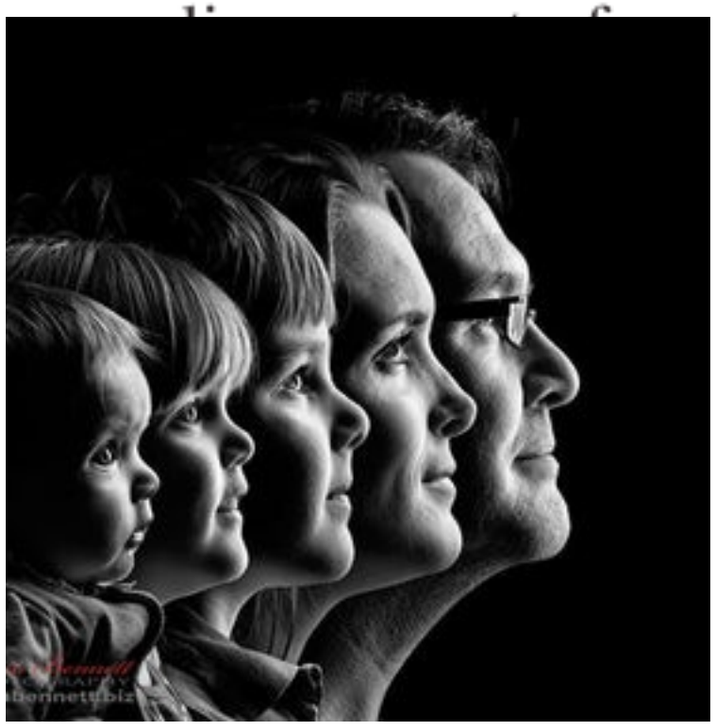
Thomas et al. 2013

Improving food safety through a One Health approach

The daily activity of producing, preparing, and consuming food directly links our health with the health of the planet in both direct and indirect ways. Over the past century, the distance between "farm" and "fork" has gone global such that the ingredients in a single meal may be obtained from numerous "local" and "global" sources. Food production and distribution for the developed world takes place across vast and complex global networks in increasingly shorter timescales. As consumers, many of us fail to recognize that our local and domestic food supplies are part of an increasingly interconnected, globalized, food production system.

Chofnes et al. 2012

Improving food safety through a One Health approach



Chofnes et al. 2012

The Well-Traveled Salad.

Do You Know Where Your Food Has Been?

As consumers, many of us fail to recognize that even our domestic and local food supplies are part of a global network. The daily activity of consuming food directly links our health as humans to the health of crops and produce, food animals, and the environments in which they are produced.

LETTUCE

Canada, Chile, Dominican Republic, Mexico, Peru, USA

CUCUMBERS

Canada, Honduras, India, Mexico, Spain, USA

FETA CHEESE

Canada, Denmark, Egypt, Germany, Greece, Israel, Italy, Turkey, UK, USA

VINAIGRETTE

Argentina, Brazil, Canada, Chile, China, France, Germany, Greece, India, Indonesia, Italy, Mexico, Morocco, Peru, Portugal, Spain, Thailand, Tunisia, Turkey, USA, Vietnam

OLIVES

Greece, Israel, Mexico, Spain, USA

SPROUTS

Argentina, Australia, Bangladesh, Canada, China, Egypt, France, India, Morocco, Nepal, Pakistan, South Africa, Spain, Turkey, USA

CROUTONS

Argentina, Australia, Brazil, Canada, China, France, India, Mexico, Netherlands, Poland, Russia, Switzerland, Uruguay, USA, Vietnam

TOMATOES

Canada, Dominican Republic, Holland, Israel, Italy, Mexico, USA

ONIONS

Canada, China, Germany, India, USA

MANDARIN ORANGES

Israel, Mexico, Morocco, South Africa, Spain

A "One Health" approach to food safety—bringing together expertise and resources from the clinical, veterinary, wildlife health, and ecology communities—has the potential to reveal the sources, pathways, and factors driving the outbreaks of foodborne illness and possibly prevent them from occurring in the first place.

NOTE: *Countries are listed in alphabetical order and not by volume of export.*

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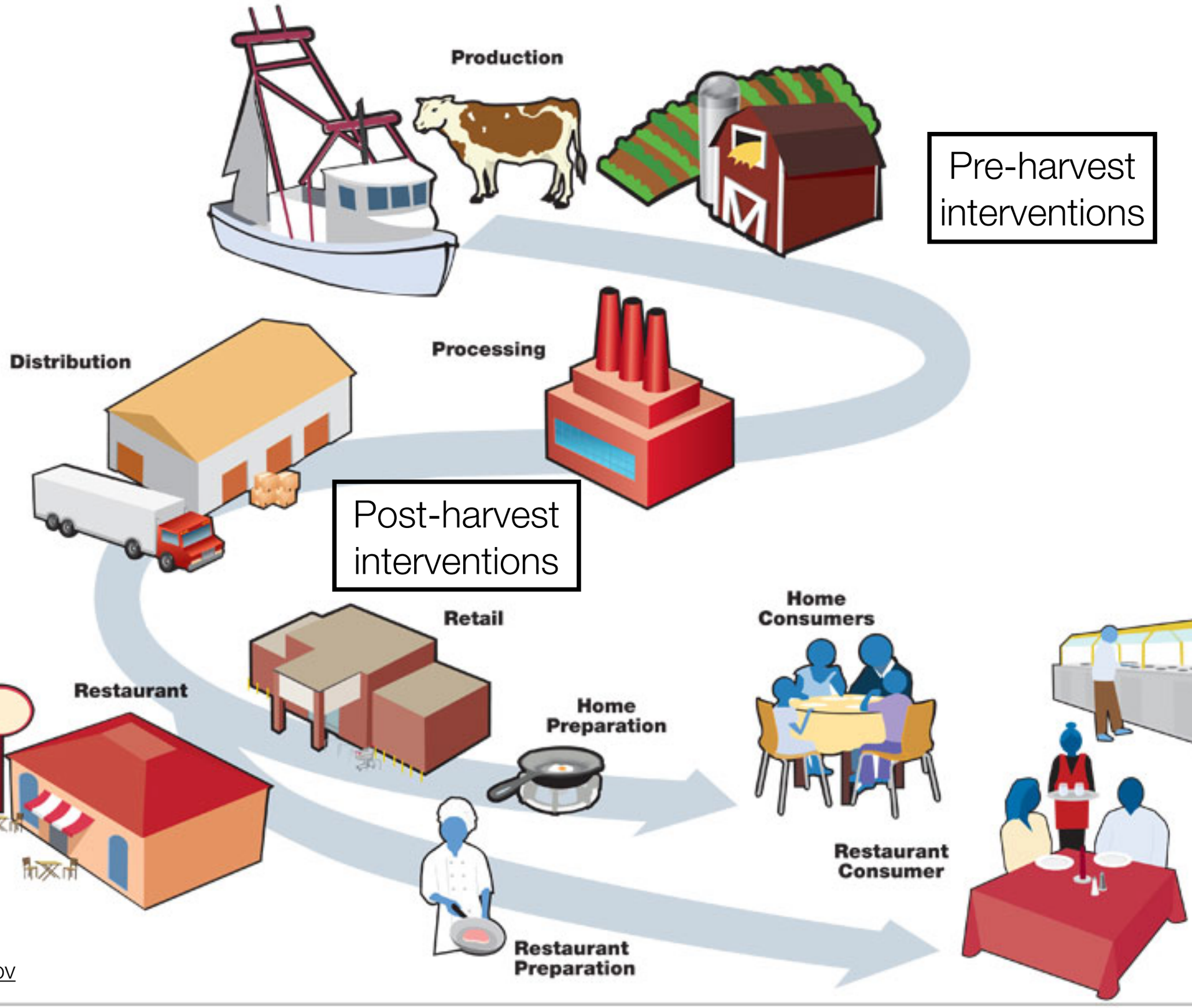
The Food Production Chain

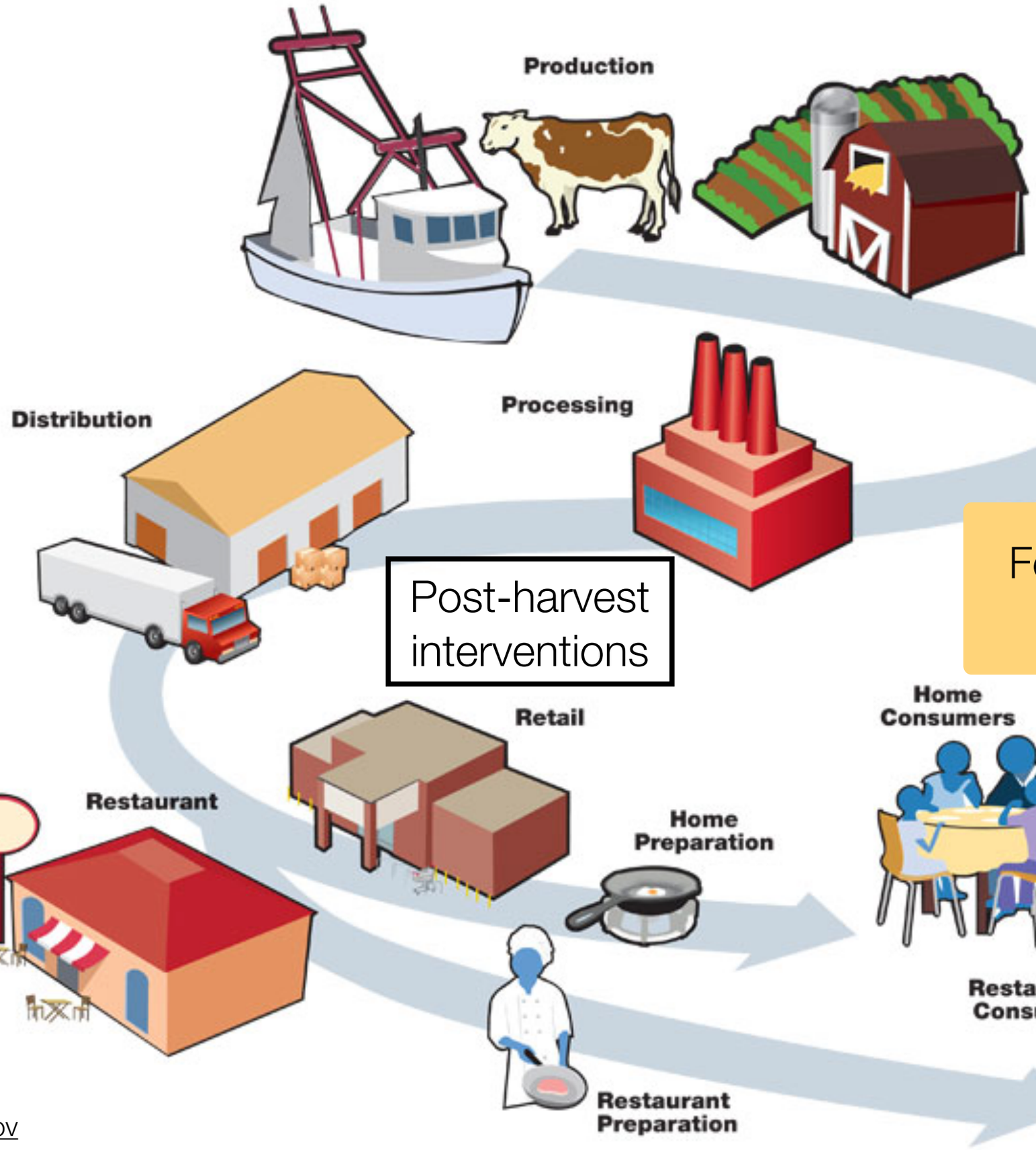


Pre-harvest interventions

Post-harvest interventions

www.cdc.gov

The Food Production Chain



Pre-harvest interventions

Post-harvest interventions

Focus on environmental exposures

www.cdc.gov

Seasonally oscillating environmental exposures

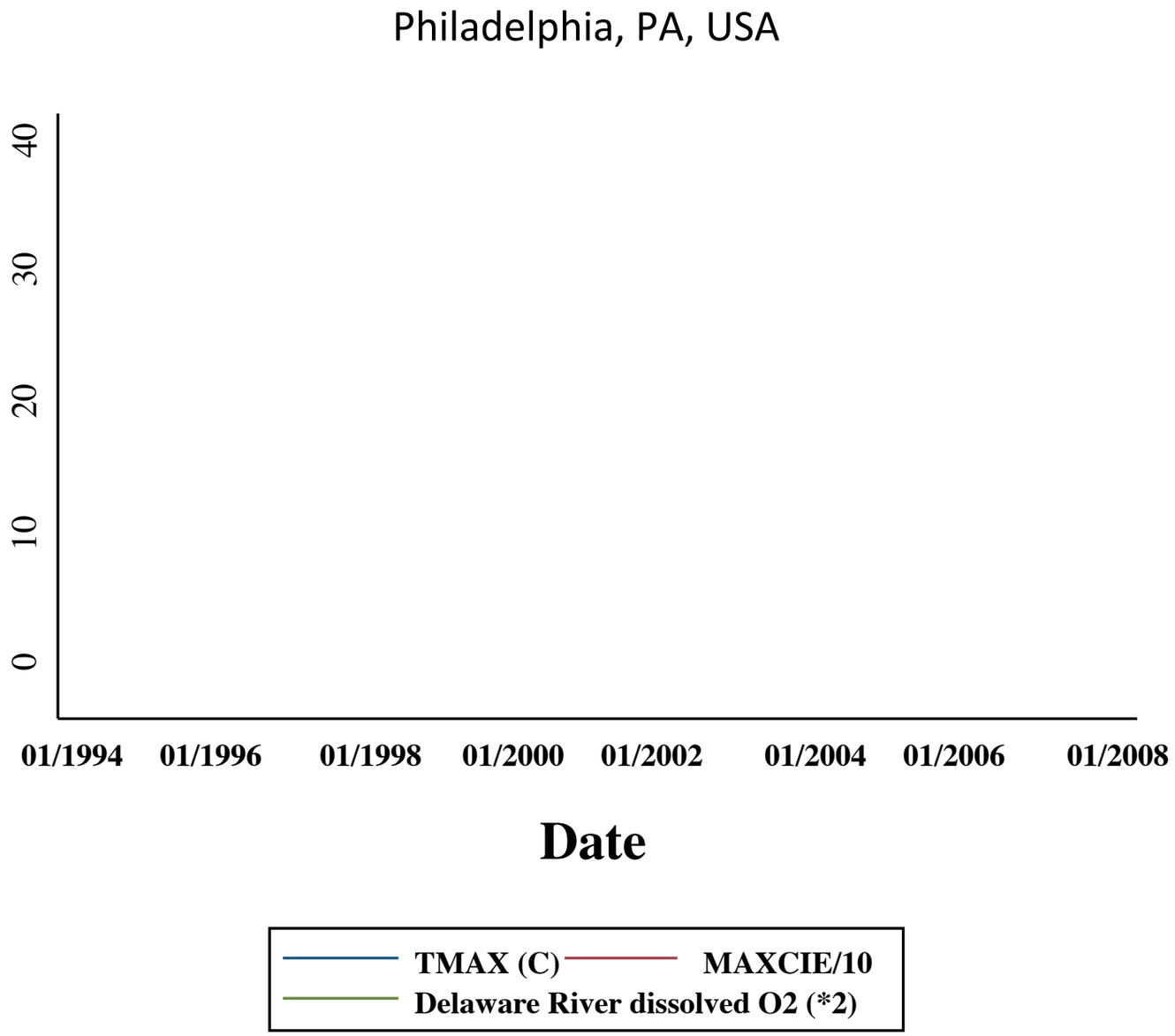
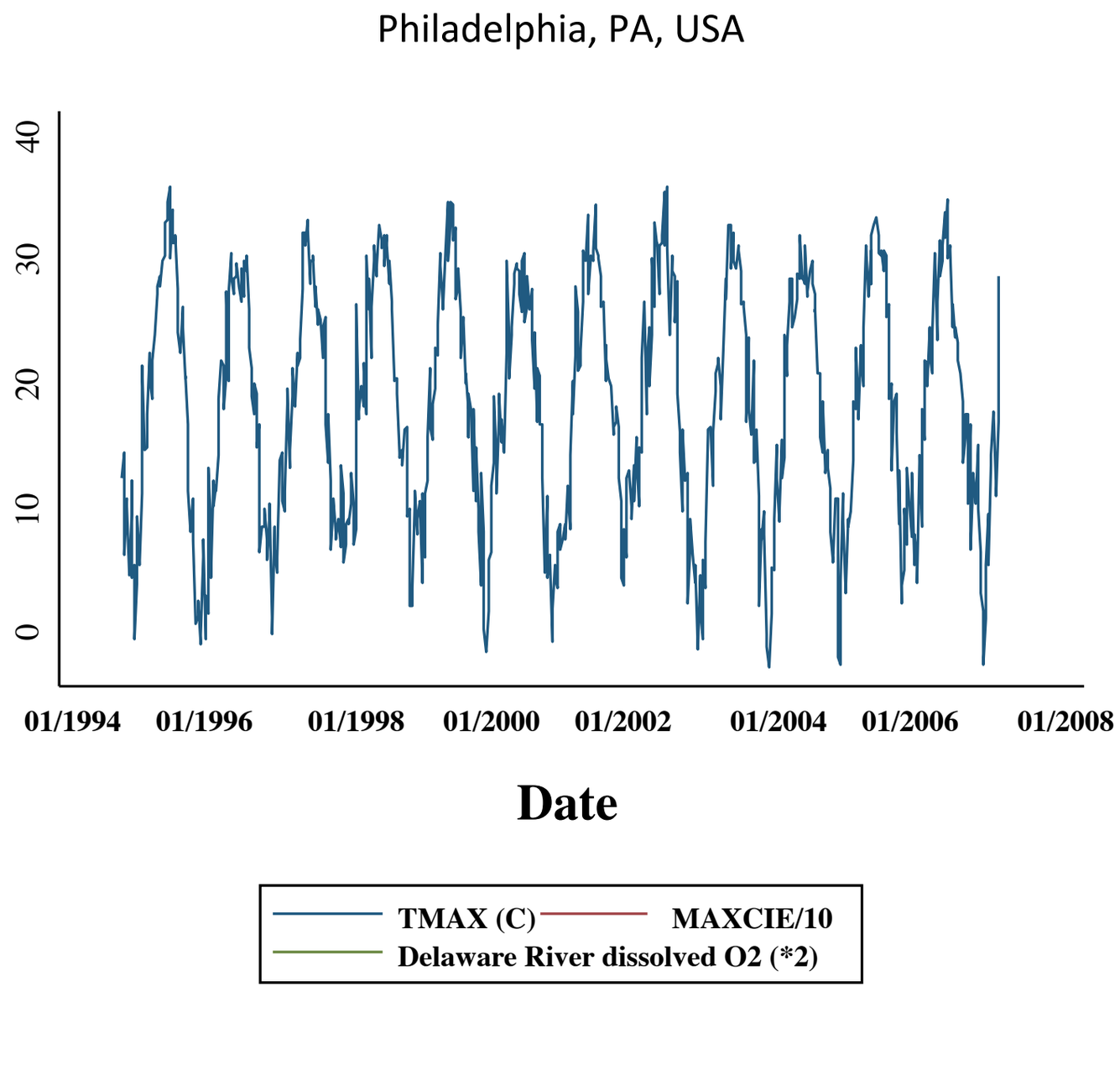


Figure courtesy of Dr. David Fisman, DLSPH

Seasonally oscillating environmental exposures



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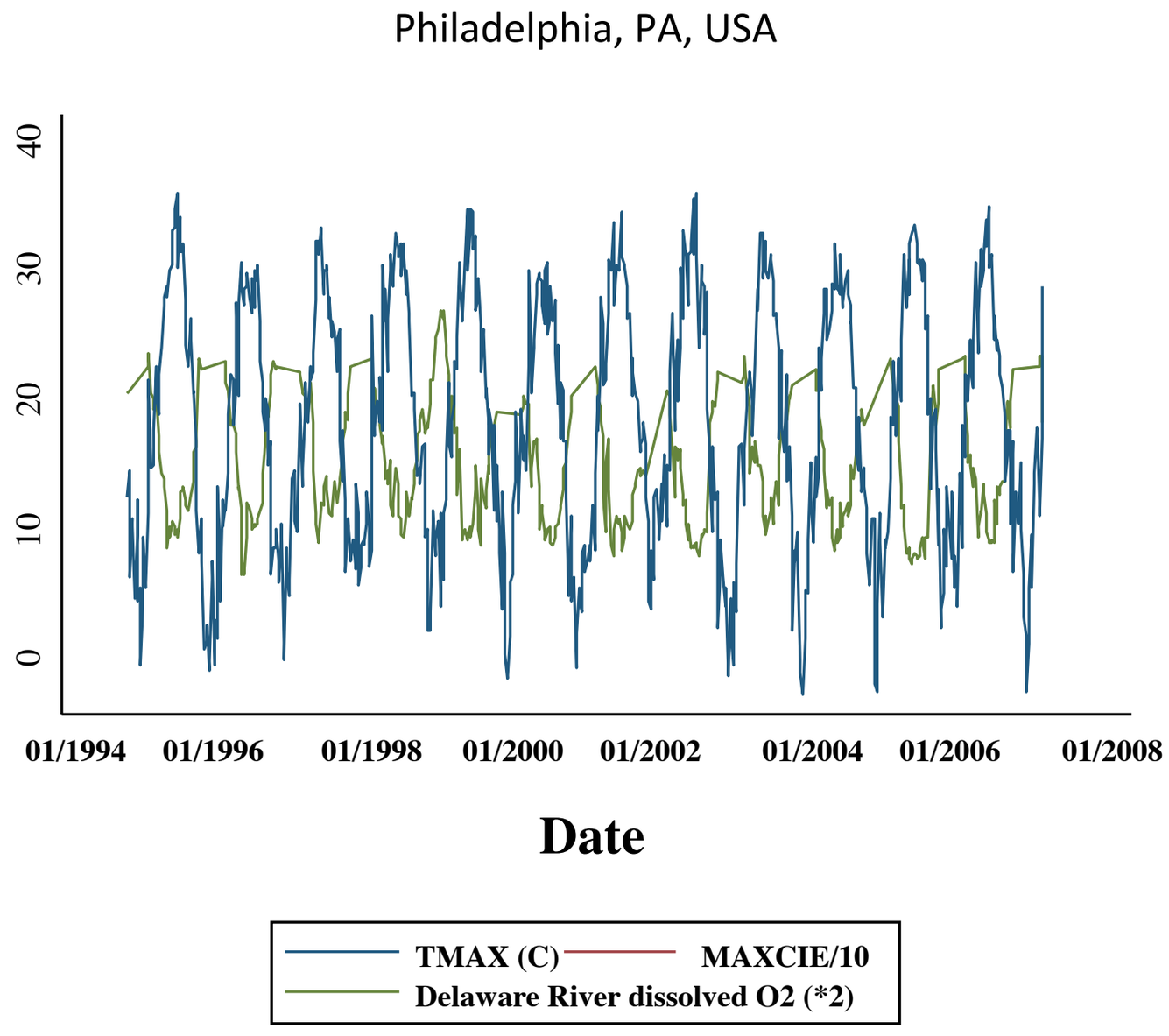

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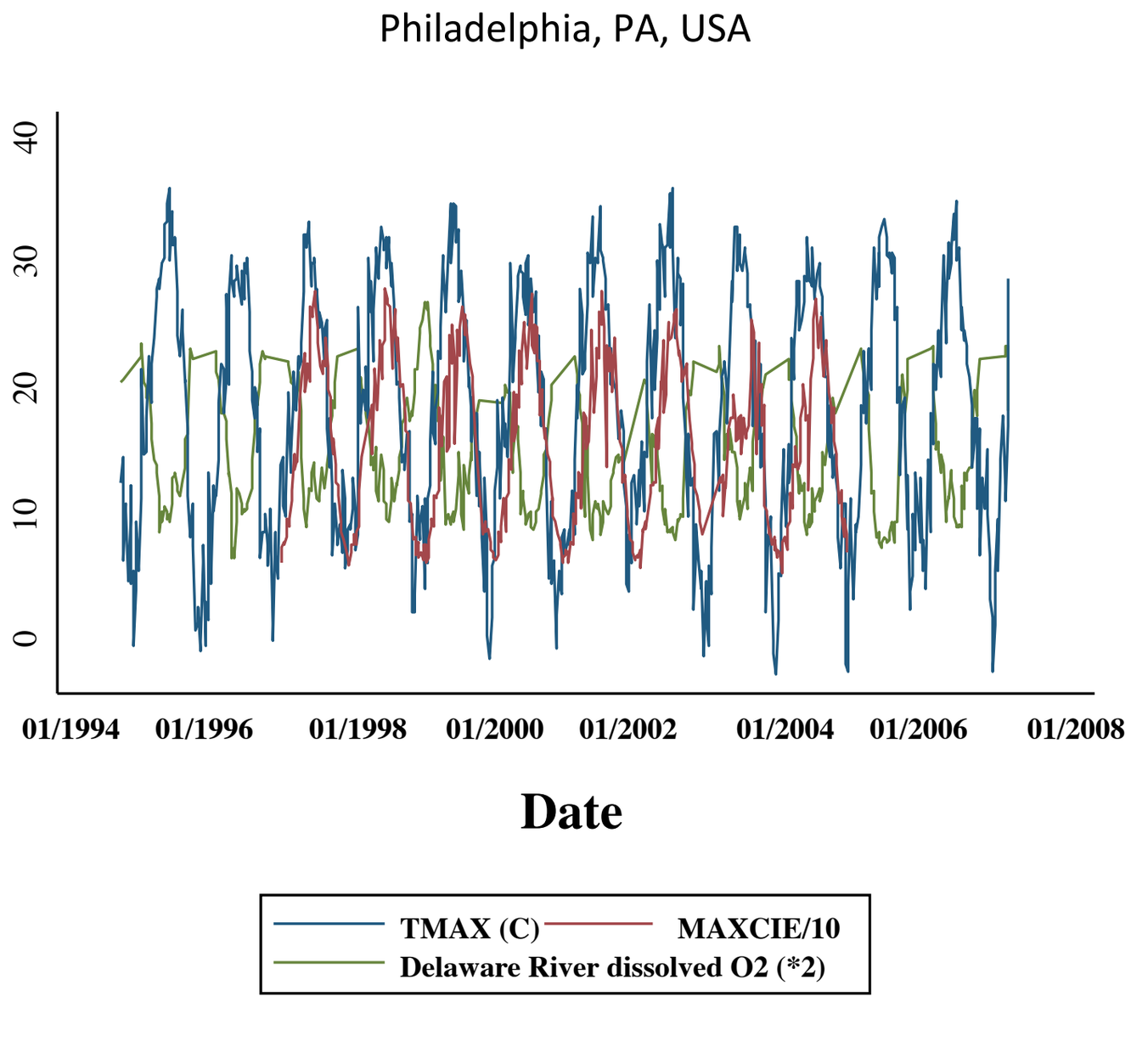

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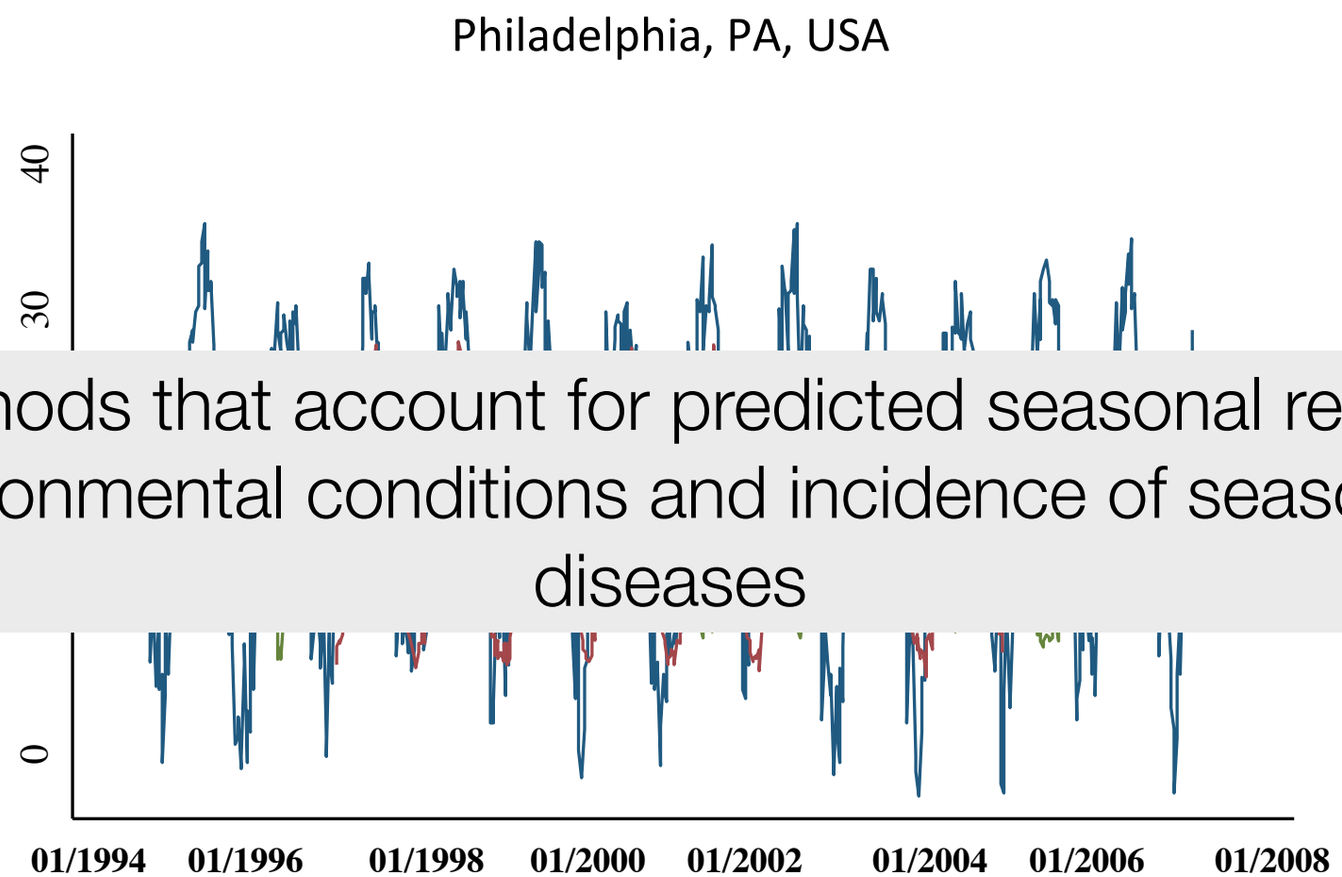


Need methods that account for predicted seasonal relationships between environmental conditions and incidence of seasonal infectious diseases

Figure courtesy of Dr. David Fisman, DLSPH

A methodological caveat

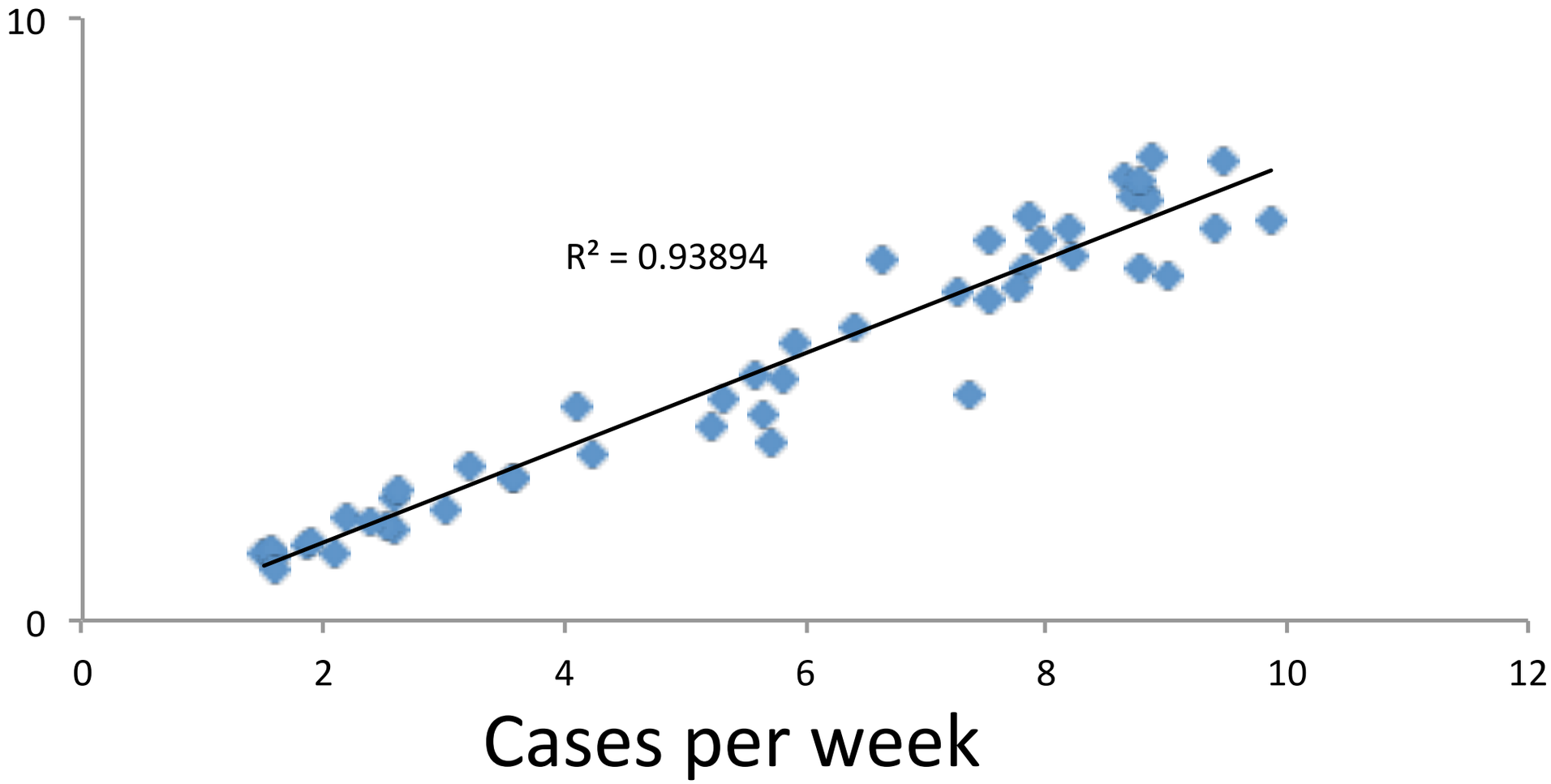
- Establishing causal links between environmental factors and disease occurrence is difficult when the disease is seasonal.

- Relationships may be confounded with underlying factors.

- Strong correlation is necessary but not necessarily sufficient.

- Aggregation of exposures may lead to “ecological fallacy”

Is it really the season?



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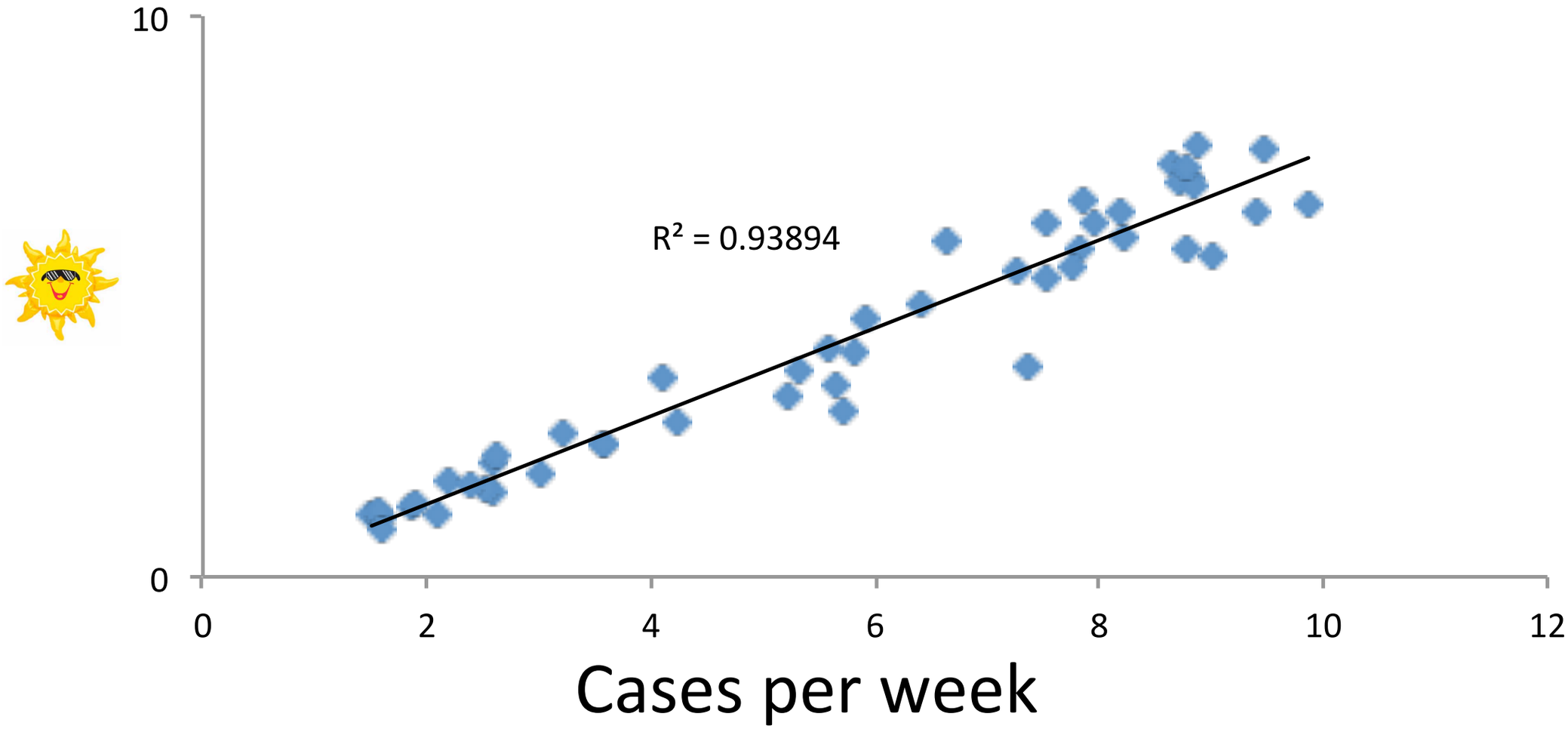

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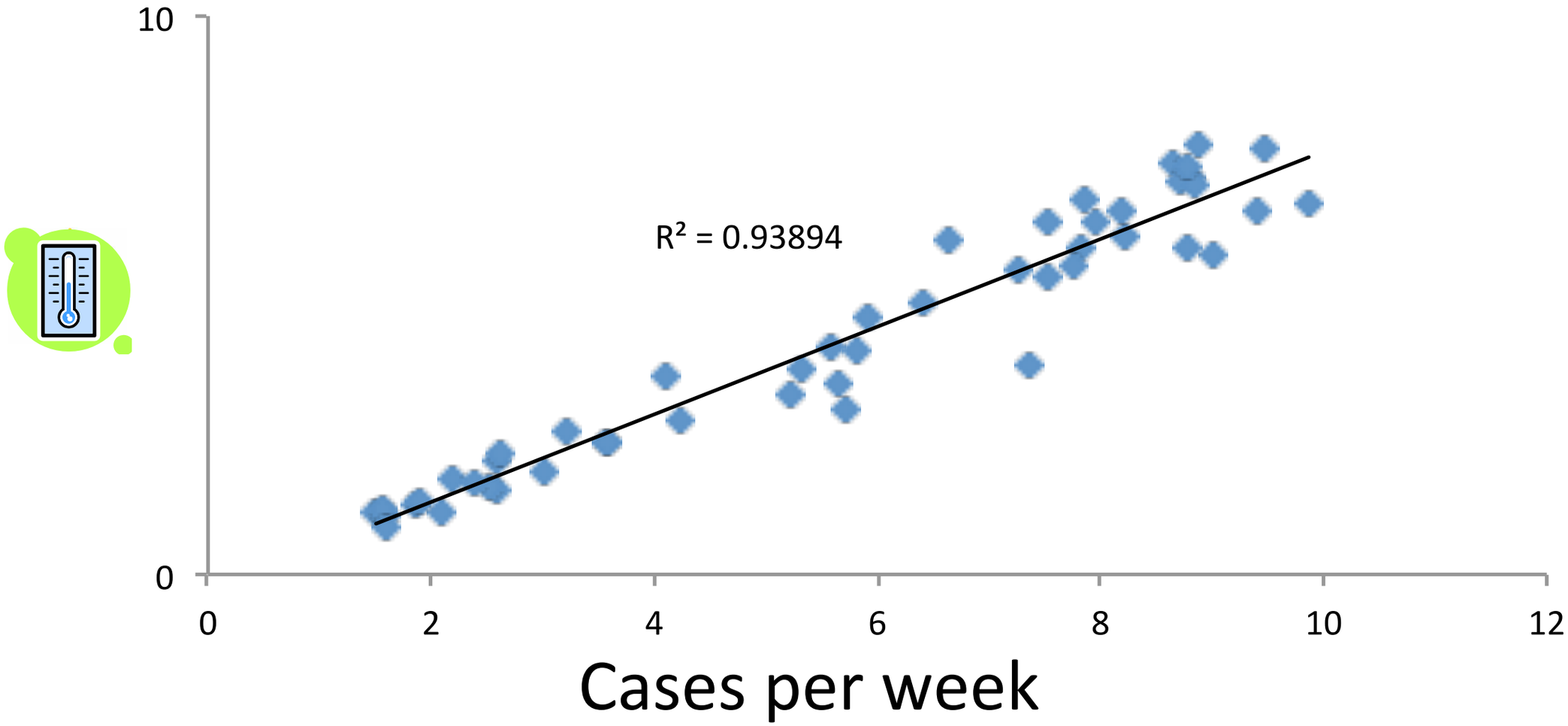

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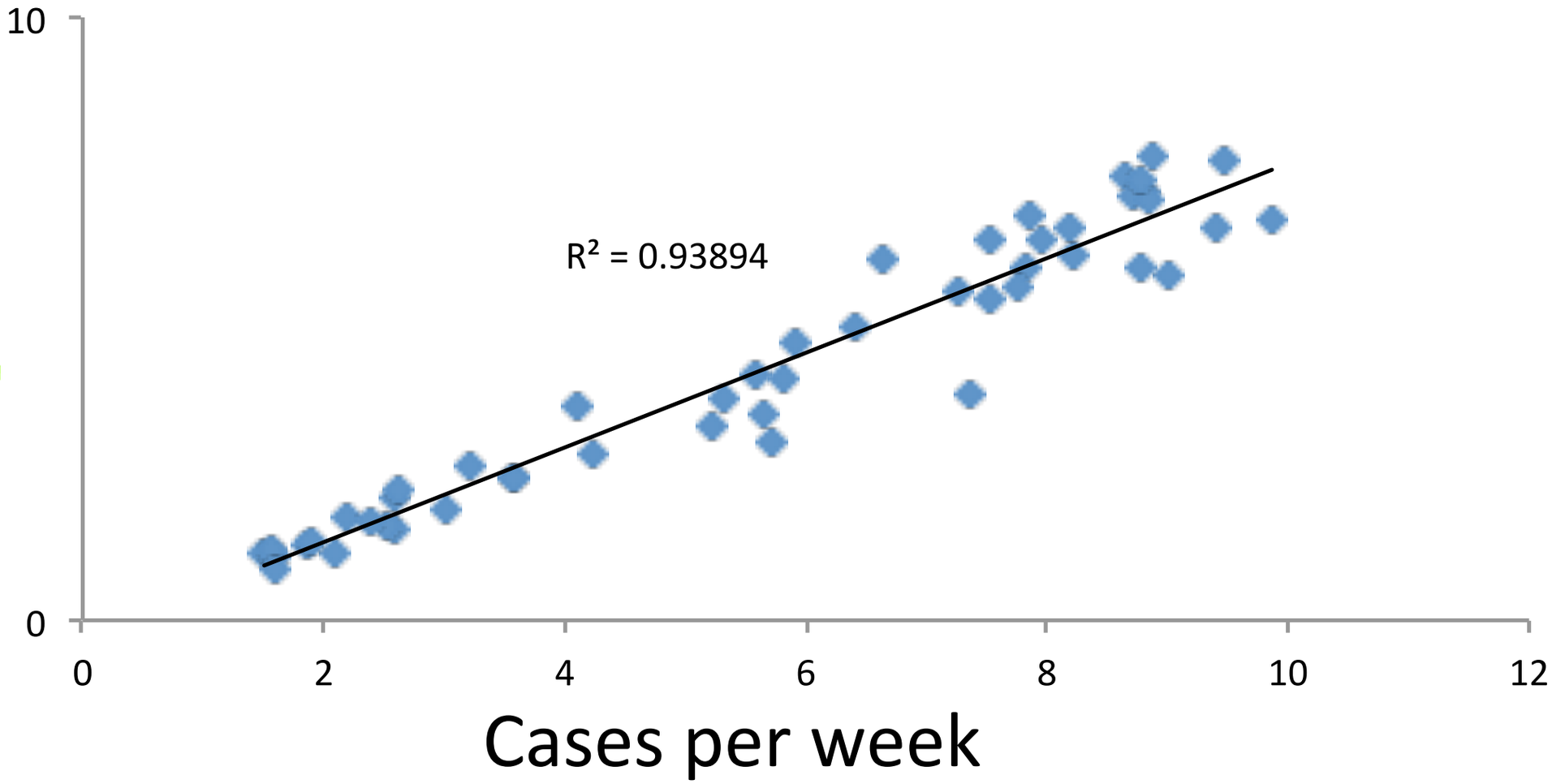

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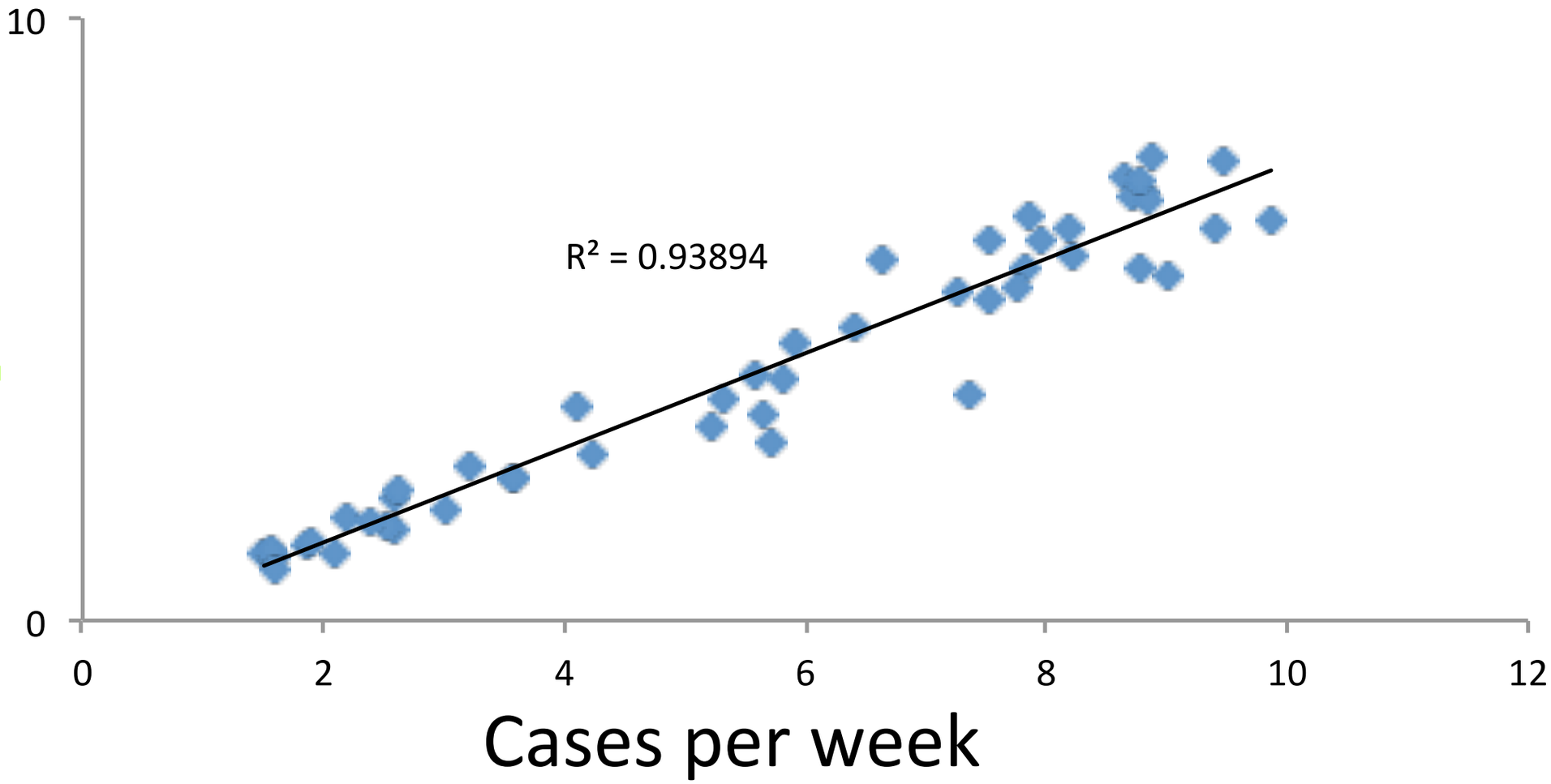


Figure courtesy of L. Kinlin & A. White

Environment and disease

What environmental factors are associated with an increased occurrence of disease?

Hypothesis

Environmental factors that increase pathogen survival, persistence, or proliferation in the environment will be related temporally and spatially to human and/or animal outbreaks or case occurrence.

Poisson regression

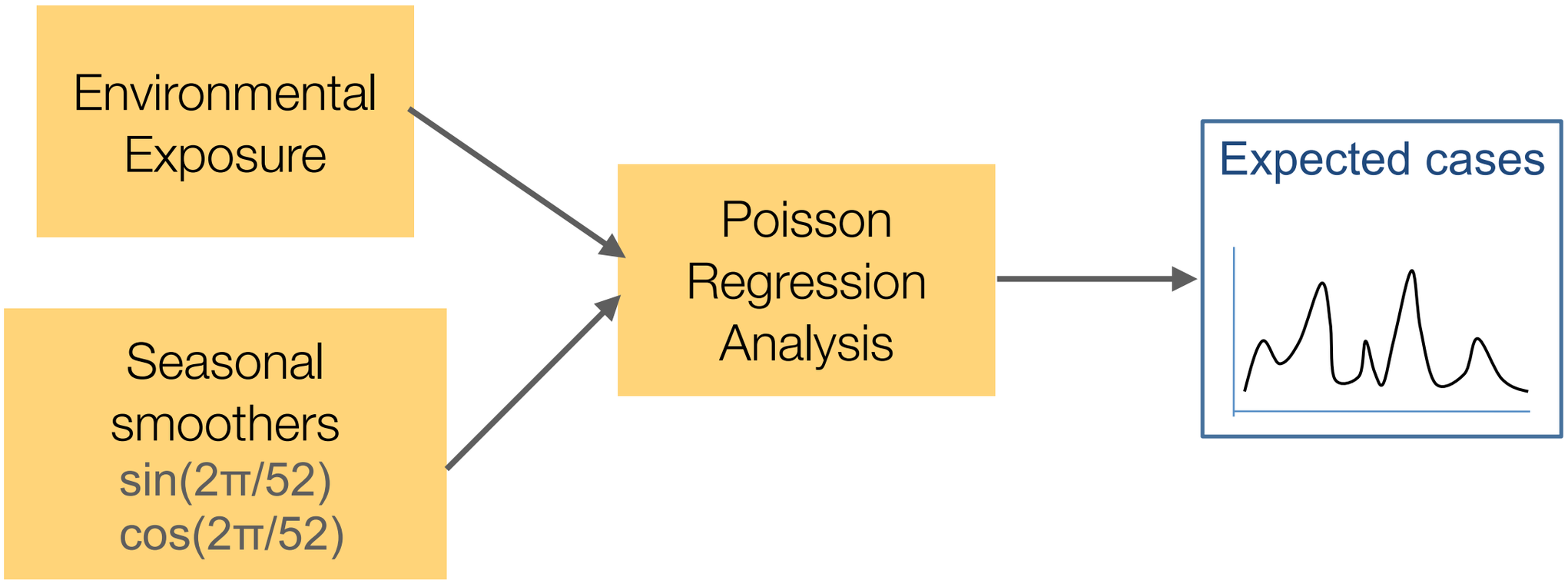


Figure courtesy of L. Kinlin & A. White

Case-crossover analysis

- Evaluate acute associations between environmental exposures and cases
- 2:1 matched design
- Random directionality of control selection

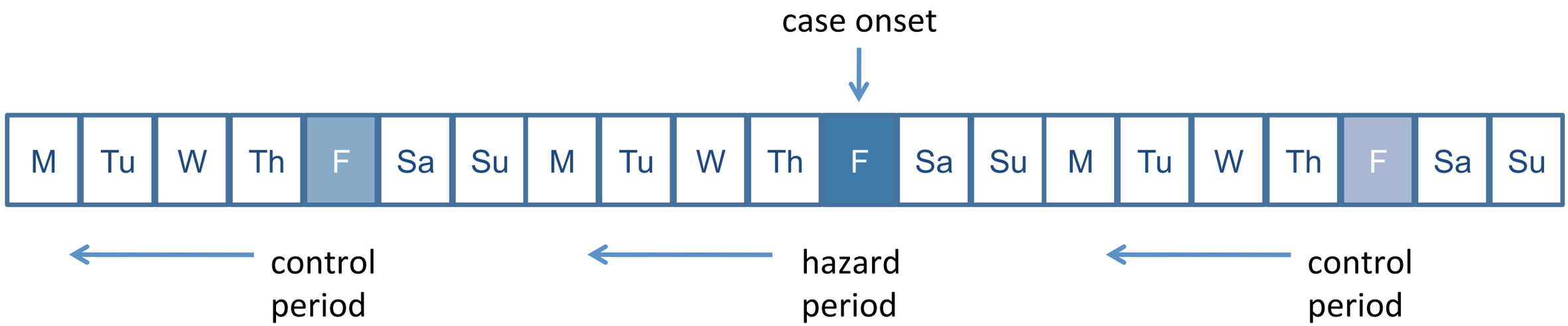
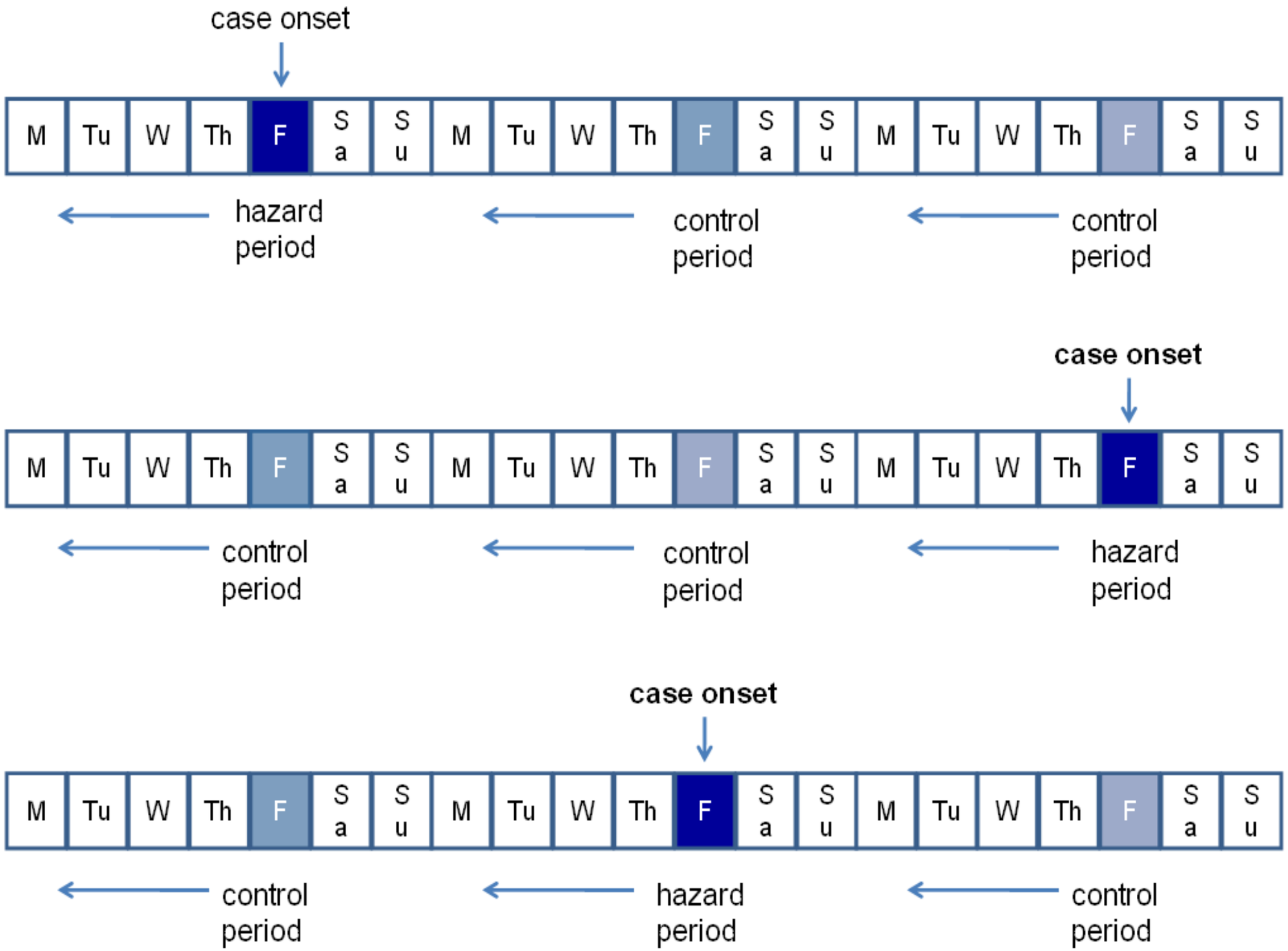


Figure courtesy of L. Kinlin & A. White
Fisman et al. 2005
Greer et al. 2009



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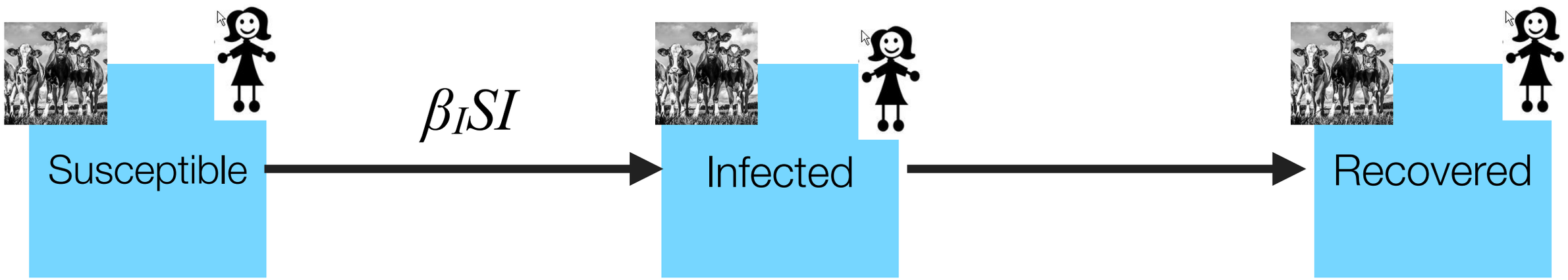
Environmental forcing in dynamic models



Eisenberg et al. 2013
Tuite et al. 2011
Tien and Earn, 2010

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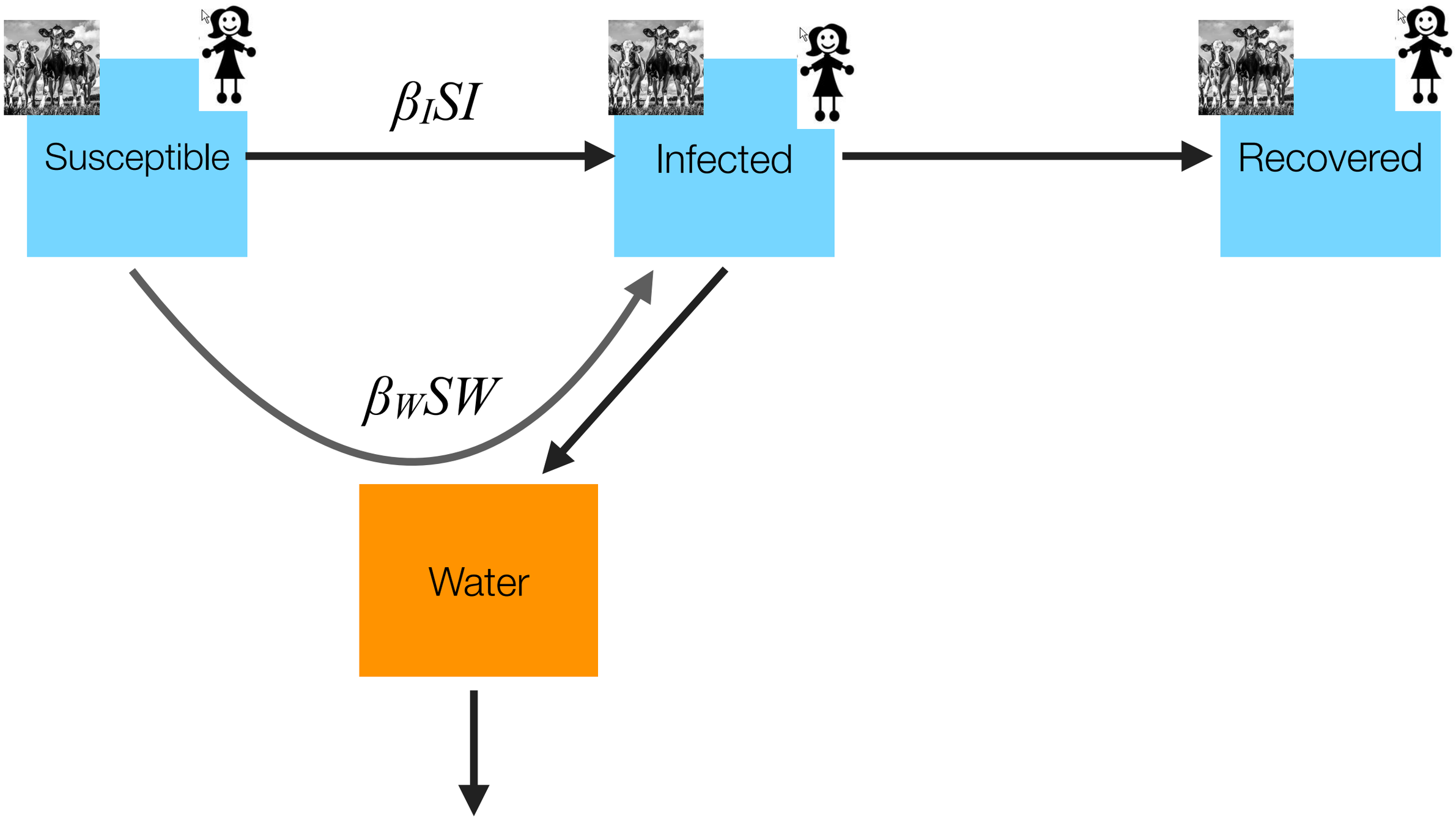

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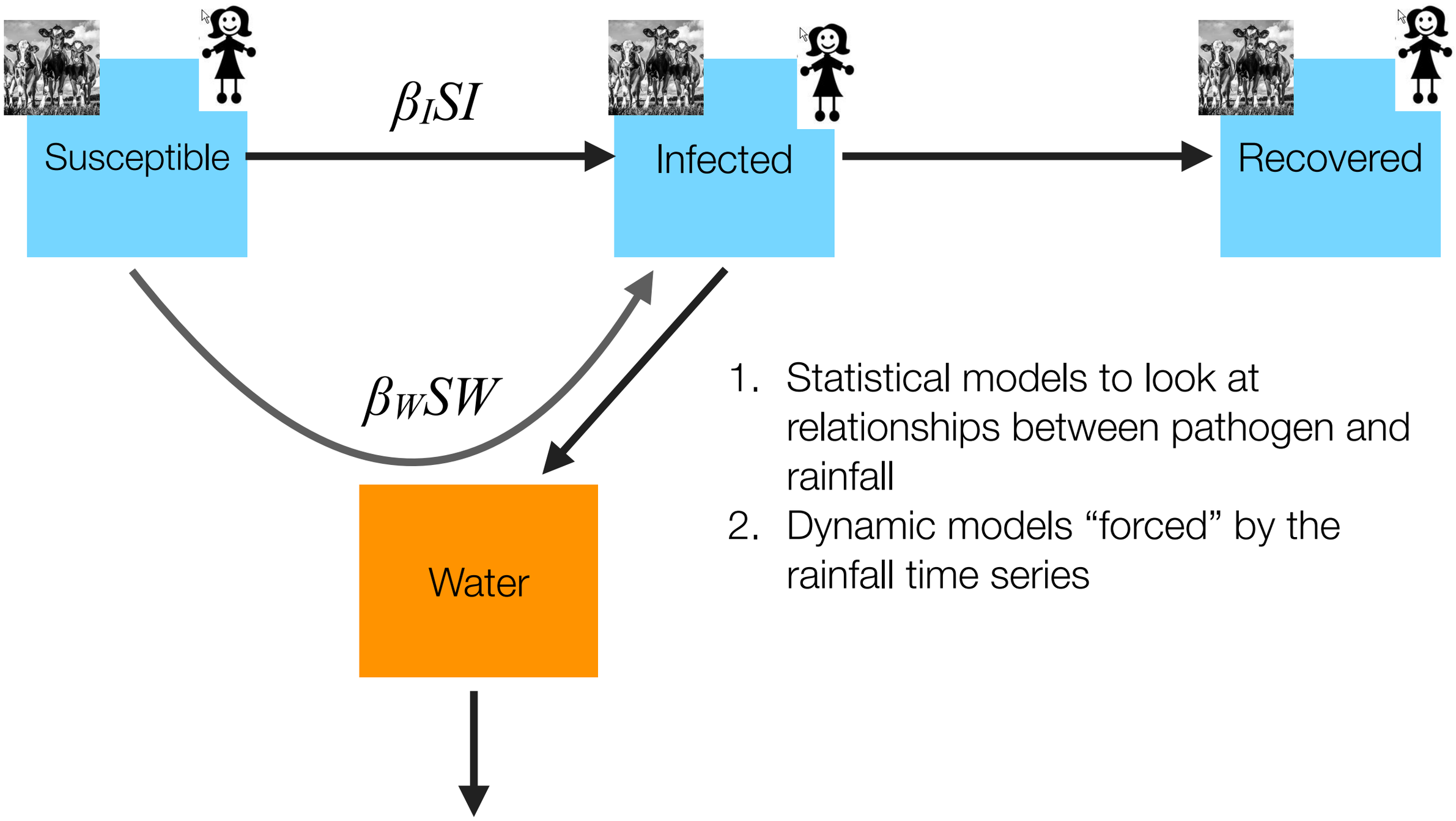

1. Statistical models to look at relationships between pathogen and rainfall
2. Dynamic models “forced” by the rainfall time series

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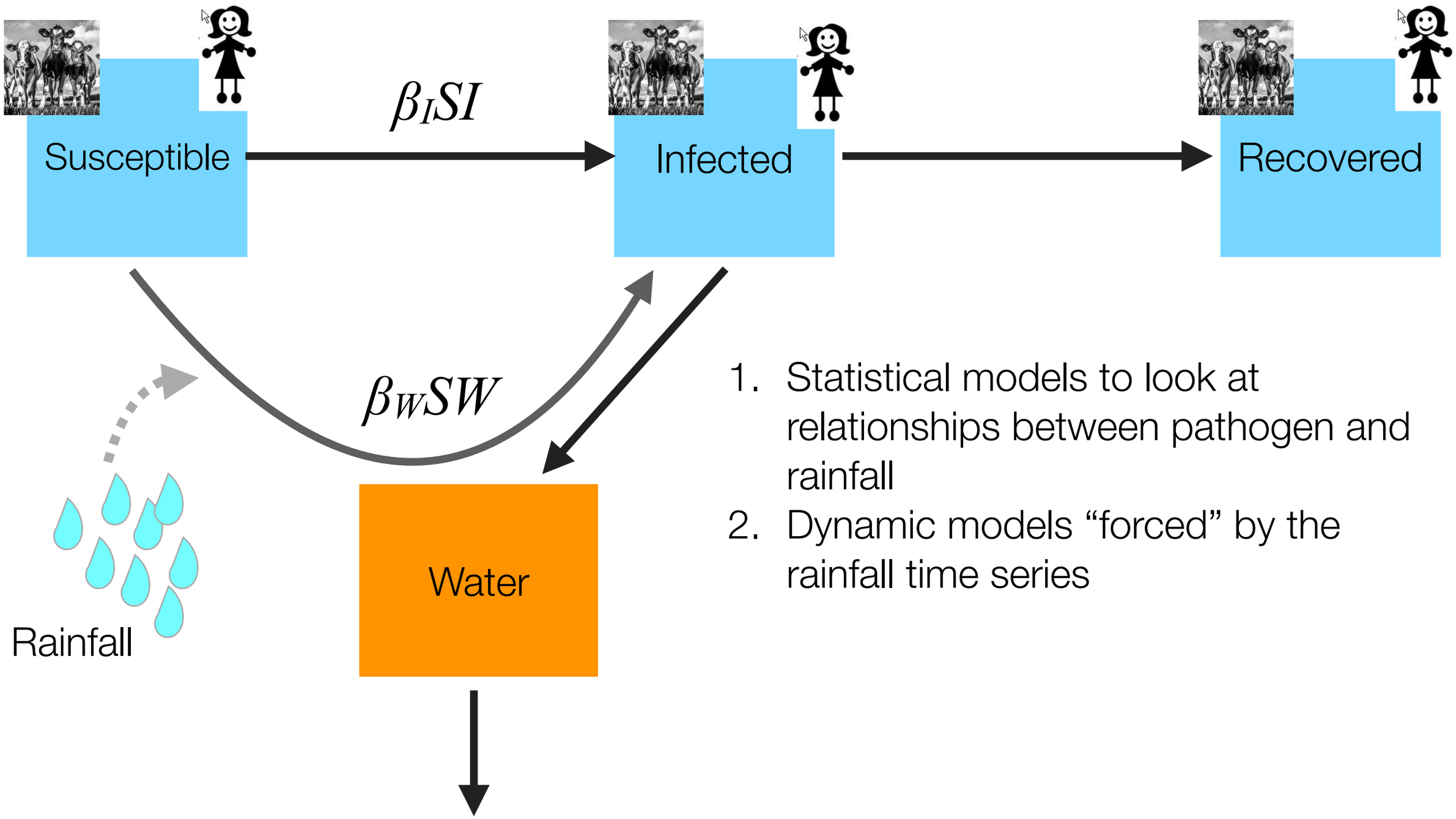

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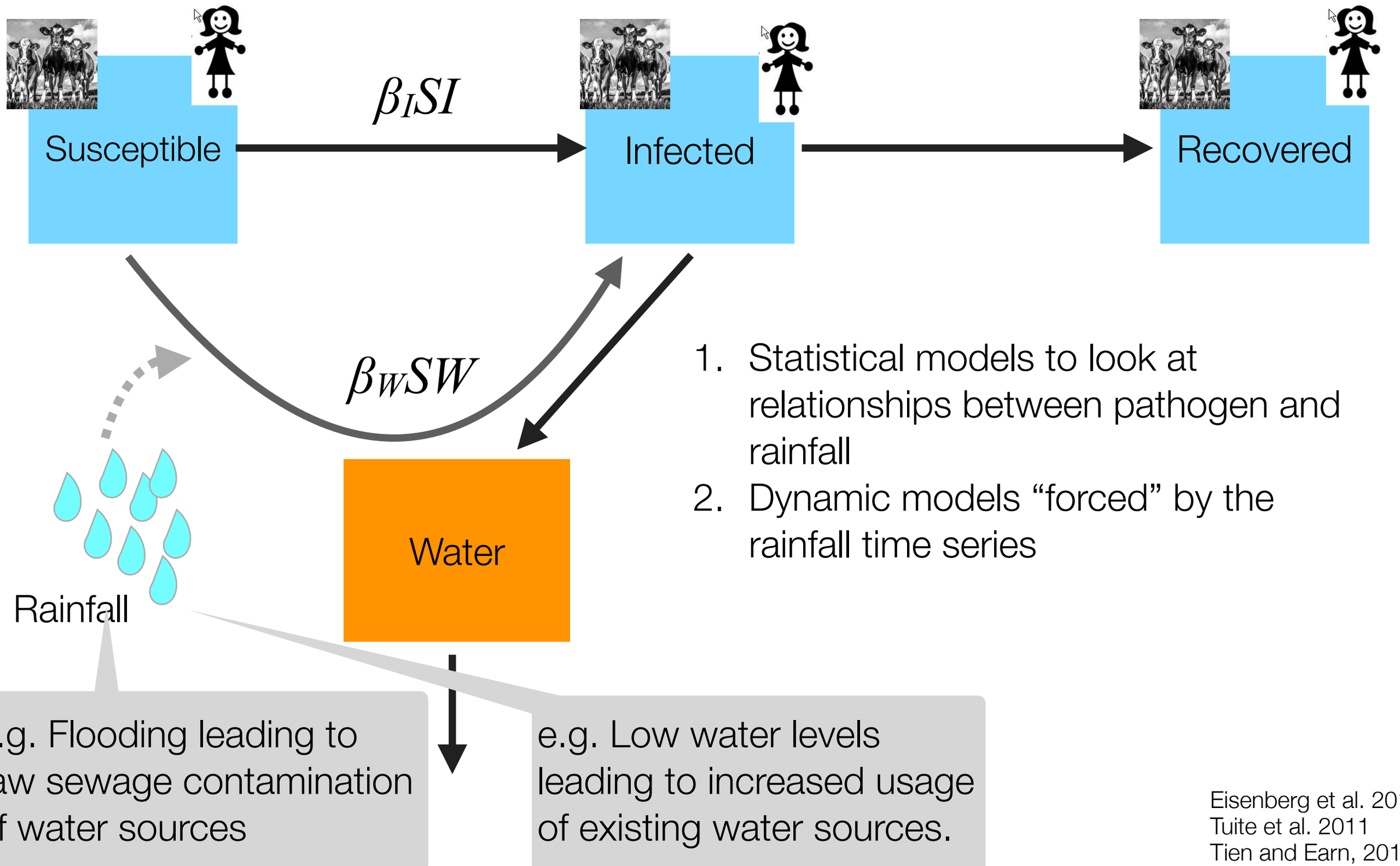

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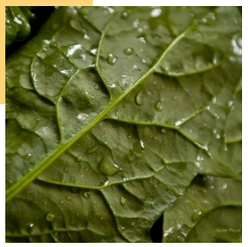
Using a “Cholera” model to think about leafy greens

Uncolonized plants

Colonized plants



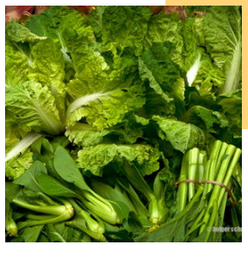
β_W

Water

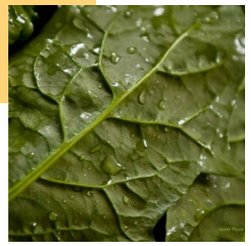
spray vs.
flood irrigation

environmental conditions, plant lifecycle

Uncolonized plants



Colonized plants



β_W

temperature, UV, humidity etc.

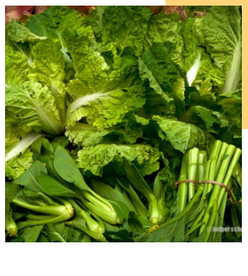
Water

Rainfall

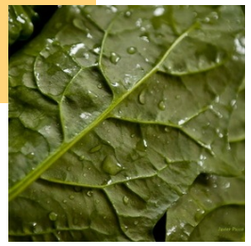
mechanism of application

environmental conditions, plant lifecycle

Uncolonized plants



Colonized plants



β_M

temperature, UV, humidity etc.

Manure

Pre-harvest interventions for animal products

1. management practices to decrease animal exposure to pathogens in the farm environment
2. reducing contacts between different species
3. prevent contamination of feed and water sources
4. surveillance for “super-shedders”
5. vaccination

Uncolonized cattle (S)

$\beta_C I$

Colonized cattle (I)

β_E

temperature, UV, humidity etc.

Farm environment

Super-shedding cattle (I_S)

Uncolonized cattle (S)

$\beta_C I$

Colonized cattle (I)

β_E

temperature, UV, humidity etc.

Farm environment

Vaccinated cattle (V)

Super-shedding cattle (I_S)

surveillance

Uncolonized cattle (S)

$\beta_C I$

Colonized cattle (I)

β_E

temperature, UV, humidity etc.

Farm environment

prevent contamination of feed and water or other environmental reservoirs

Health economic challenges for One Health

- Is the intervention good value for money?
- Societal and governmental perspectives consider all direct and indirect costs regardless of to whom the costs are accrued.

An example

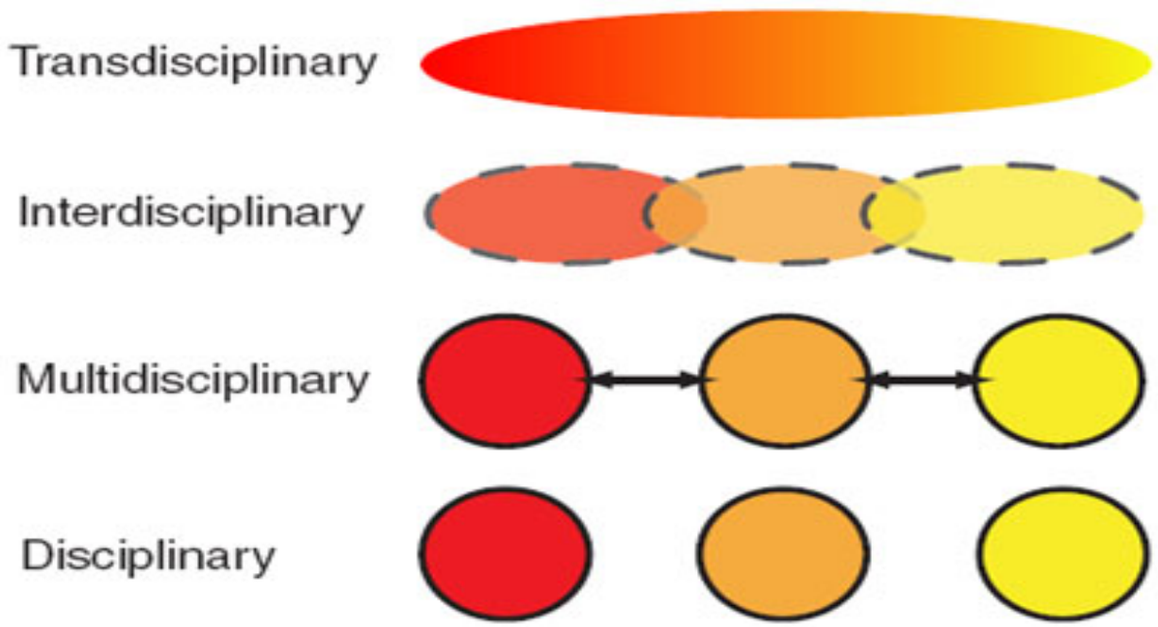
There are no direct economic implications for farmers with VTEC colonized cattle.

Farmers pay out of pocket for vaccine (economic loss for farmers)

Healthcare system benefits as a result of farmers out of pocket expenses with no benefit being seen by the farmers.

Conclusions

- Mathematical models provide us with a unique framework within which to examine the complex biological dynamics at the human-animal-environment interface.



Colon et al. 2008