An Evaluation of the Costs Associated with Implementing Management Strategies for Control of *Brucella abortus* in Yellowstone Bison and Elk

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Agricultural Economics & Economics
Mountains & Minds

Outline

- Background Information
  - *Brucella abortus* in the GYA
  - Economic Importance
  - Management Strategies
- Study Plan for Estimating Management Costs
  - Objectives
  - Analytical Approach
  - Examples
  - Project Challenges

Caveat:

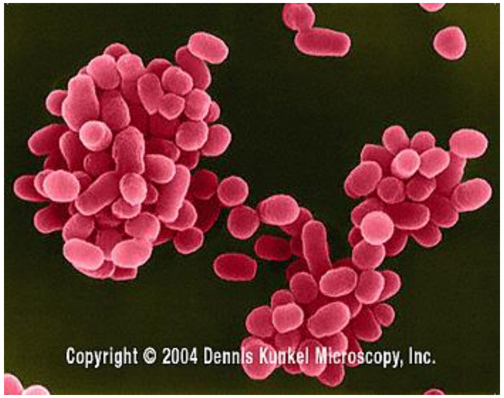
- We are Economists
  - Economic analysis of any industry requires knowledge of institutional details.
  - In the present context, obtaining defensible estimates of costs will require learning about analogous details related to the science of Brucellosis.

Caveat:

- This science is complex and not perfectly understood.
- There are many studies and papers in professional journals.
- Interaction with science experts will be essential.
- Our current level of understanding of biology?
  - Starting to scratch the surface . . .

Background

- Disease agent *Brucella abortus*
- Reproductive disease
  - Abortions, stillbirths, infertility, and reproductive lesions
  - Wildlife (bison, elk) and domestic livestock (cattle)
- Transmission is through ingestion of *Brucella abortus*
  - Contact with fetuses, placenta, and birth fluids
- Zoonotic disease



Background

- Historically brucellosis was endemic in U.S. cattle herds
- 1934: federal-state cooperative program
- Today prevalence in cattle herds has dropped to 0.0001% through depopulation and vaccination efforts
- Brucellosis is now common to GYA elk and bison
  - 40-60% of Yellowstone bison are seropositive
  - Increasing seroprevalence in Yellowstone elk herds

Transmission: Intra-Species

- Young females are an important source of infection
- Transmission occurs during and after birthing or abortion events
- Some infected animals clear the disease and others become chronic

Transmission: Inter-Species

- Spatial overlap between wildlife and cattle
  - Calving season, January-June
- Contact with environmental sources
  - *B. abortus* survived up to 43 days at natural birth and abortion sites (Aune et al. 2012)

No documented transmission between cattle and bison in the wild

All recent GYA cattle infections from wildlife trace back to elk

Effects of Brucellosis on the Cattle Industry

- Economic losses to producers arise from:
  - Reduced reproductive efficiency
  - Reduced marketability
  - Whole herd depopulation
  - Test and removal with quarantine
  - Development of a management plan

Brucellosis Instances in Domestic Livestock within the GYA

- 2002-2012
  - 17 instances identified
  - In Wyoming (7), Idaho (5), and Montana (4)
  - Cattle (13 herds)
  - Bison (3 herds)

- 2013-2014
  - Additional instances have been identified
  - 2 - 3?
  - In Montana?

Brucellosis Cases in Domestic Livestock within the GYA

- 2002-2012
  - 17 cases

Table. Cattle and ranched bison herds found infected with *Brucella abortus* due to transmission from elk, Greater Yellowstone Area, USA

Herd no.	County, state	Species	Herd size	Date detected	Seropositive, %	Culture results	Distance to feeding ground, km
1	Fremont, ID	Cattle	50–100	2002 Apr	12.0	Biovar 1	50*
2	Sublette, WY	Cattle	>300	2003 Oct	9.9	Biovar 1	2.4
3†	Teton, WY	Cattle	>300	2004 Jun	1.9	Biovar 4	Adjacent
4	Bonneville, ID	Cattle	<50	2005 Aug	20.0	Biovar 1	85‡
5	Park§, MT	Cattle	>300	2007 May	0.2	Biovar 1	>100
6	Park, MT	Cattle	<50	2008 May	2.9	Biovar 1	>100
7	Sublette, WY	Cattle	>300	2008 Jun	5.5	Biovar 4	24
8	Jefferson, ID	Cattle	>300	2009 Jul	1.5	Biovar 1	85
9	Park, WY	Cattle	>300	2010 Oct	1.1	Biovar 1	>100
10	Park, WY	Bison	200–300	2010 Nov	11.5	Biovar 4	>100
12	Park, WY	Cattle	>300	2011 Feb	0.9	Biovar 1	>100
13	Park, WY	Cattle	>300	2011 Sep	1.2	Biovar 1	>100
14	Park, MT	Cattle	>300	2011 Sep	2.0	Biovar 1	>100
15	Madison, MT	Bison	>300	2011 Nov	0.2	Biovar 1	>100
16	Fremont, ID	Cattle	50–100	2012 Apr	5.8	Biovar 1	90
17	Bonneville, ID	Bison	200–300	2012 Mar	0.7	Biovar 4	40

*Elk were also intentionally fed on ranch by owner.
†Brucellosis was detected in 2 herds that were pastured together during spring of 2004. This was considered a single transmission event, and statistics are given for the combined herds.
‡Herd located 0.8 km from site where elk feeding ground had been until 2003.
§This herd was discovered infected in Carbon County, MT, in 2007, but animals had been transported from Park County in 2005. Index cow aborted in 2005 and did not calve in 2006.

Rhyan et al. 2013 Emerging Infectious Diseases

Brucellosis Cases in Domestic Livestock within the GYA

- 2013-2014

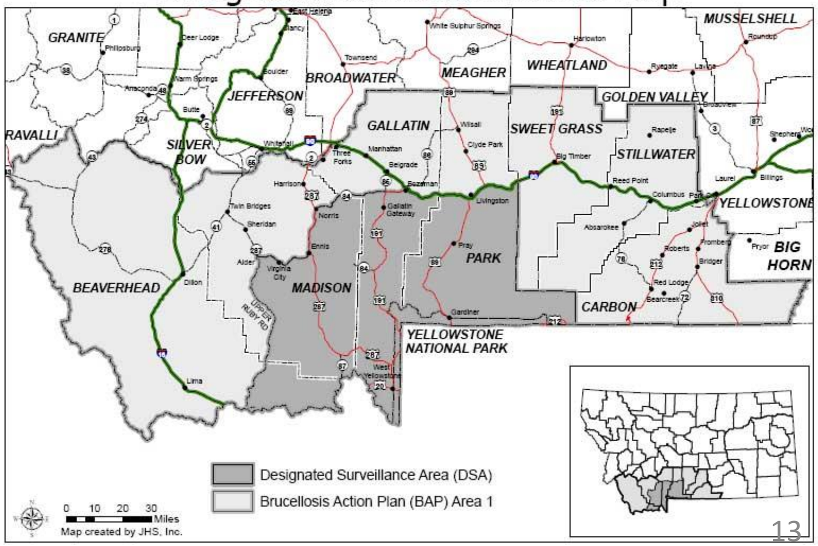
State/ FY	Method of Detection	Herd Type	Affected Herd Management Plan	Genotyping Descriptive Results	Wildlife Surveillance Planned	Animals Being Traced	States Receiving Traced Cattle/ Bison
MT 2014	Certified Brucellosis-Free Herd Recertification Test	Beef	Quarantine with test & remove	Clusters with other isolates recovered from area wildlife & domestic livestock	Yes	59	**One trace-in State:** MT, 1 herd **~8 trace-out States:** Identification of States & animals to be finalized
MT 2013	DSA Required pre-slaughter testing	Beef	Quarantine with test & remove	Common ancestor with wild elk from the same area	Yes	362	**~4 trace-out States:** Identification of States & animals to be finalized

APHIS Dec 2013 Brucellosis Surveillance Results

Regulations for Brucellosis Outbreaks in Domestic Livestock

- Until recently, an entire state's disease free status was at risk when positive herds were detected
  - Whole herd depopulation was required.
- In 2010, Designated Surveillance Area (DSA) was created in the GYA.

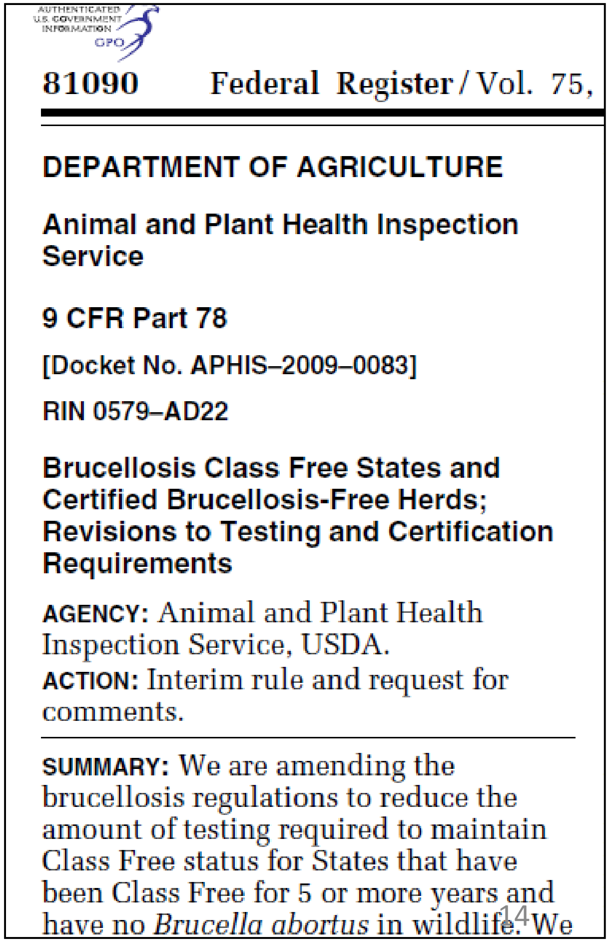
Brucellosis Action Plan and Designated Surveillance Area Map



Regulations for Brucellosis Outbreaks in Domestic Livestock

- Now, finding a positive herd in the DSA threatens disease-free status only in the DSA.
- There are also a variety of requirements for cattle in the DSA related to
  - Vaccination
  - Testing
  - Identification

– And, test and removal with quarantine has replaced whole herd depopulation



AUTHENTICATED U.S. GOVERNMENT INFORMATION GPO

81090 Federal Register / Vol. 75,

DEPARTMENT OF AGRICULTURE

Animal and Plant Health Inspection Service

9 CFR Part 78

[Docket No. APHIS–2009–0083]

RIN 0579–AD22

Brucellosis Class Free States and Certified Brucellosis-Free Herds; Revisions to Testing and Certification Requirements

AGENCY: Animal and Plant Health Inspection Service, USDA.

ACTION: Interim rule and request for comments.

SUMMARY: We are amending the brucellosis regulations to reduce the amount of testing required to maintain Class Free status for States that have been Class Free for 5 or more years and have no *Brucella abortus* in wildlife. We

Brucellosis Control Methods Currently Used for Yellowstone Wildlife

- Bison
  - Test and removal (culling) at the YNP boundary
  - Limited vaccination at YNP boundary and remotely
  - Spatial-temporal separation (hazing, etc.)

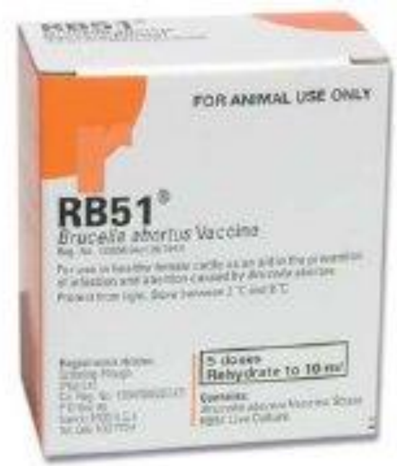
- Elk
  - Few management strategies in place
  - Elk fences
  - Currently no remote vaccination
  - Feedgrounds?

Effectiveness of, e.g., Bison Culling

- This is a primary method for controlling brucellosis in Yellowstone bison
- Seropositive animals are removed
- Tests are unable to distinguish between active and inactive infections
- Reduces herd immunity
- Ineffective at substantially reducing brucellosis (Treanor et al. 2011)

Issues Associated with Vaccinating Livestock and Wildlife

- Shows potential for reducing Brucellosis
- Efficacy of the current vaccine (RB51) is limited:
  - Somewhat effective at reducing abortions
  - Less effective at reducing animal infection
  - Less effective in wildlife than cattle
- Delivery Issues:
  - Manual vs Remote (bio-bullets)
  - Costs? Effectiveness?
- Other vaccines on the horizon:
  - Improved versions of RB51?
  - DNA vaccine (Clapp et al. 2011)?
  - Research progress delayed since 9/11

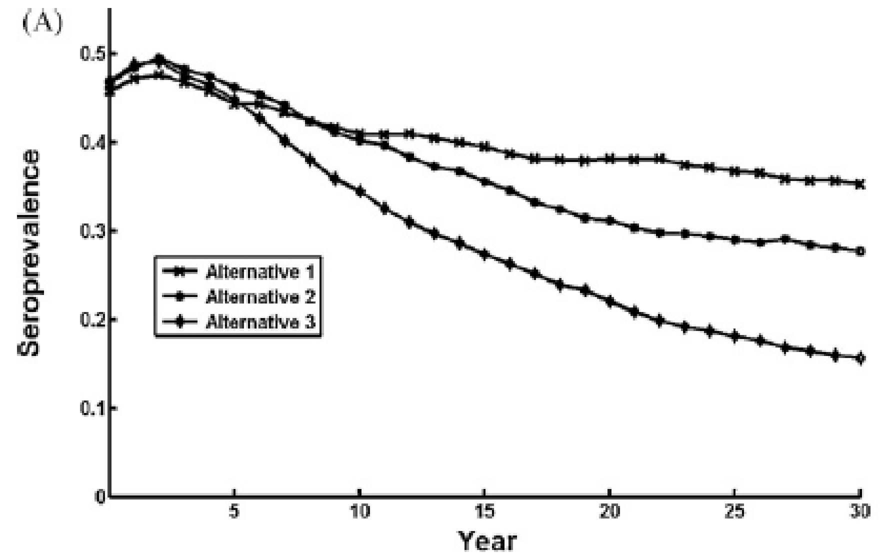


Possible Management Objectives and Methods?

- Management objectives for reducing domestic livestock infection
  - Eradication of brucellosis in wildlife
  - Reduction of brucellosis in wildlife
  - Separation of wildlife from domestic livestock
- Methods
  - Vaccination (wildlife and/or domestic livestock)
  - Test and removal
  - Sterilization
  - Hazing
  - Hunting
  - Others?

Recent Research: Results of Modeling Studies

- Vaccination
  - *Treanor et al. 2010* found a 66% reduction in brucellosis seroprevalence when 29% of female bison were vaccinated with a 50% efficacious vaccine over 30 years
- Sterilization
  - *Ebinger et al. 2011* found sterilization of 75-100 head eradicated brucellosis in under 35 years
- Test and removal
  - *Hobbs et al. 2014* found a 19 fold increase in the probability of reducing seroprevalence below 40% when seropositive females were removed versus no action plan



Treanor et al. 2010 Vaccine

Note: No cost estimates.

Recent Research: Costs of Brucellosis Outbreaks in Cattle

- Wilson 2011 estimated producer costs under the previous management regime.

- No cost estimates exist under the current policies.

Recent Research: Cost and Benefits of Alternative Wildlife Brucellosis Management Strategies?

- Roberts et al. 2011 estimated the economic incentives to cattle producers from implementing brucellosis prevention activities
- Kauffman et al. 2011 assessed costs and benefits of controlling brucellosis in elk to reduce economic losses associated with cattle outbreaks
- A cost-assessment of management strategies for Yellowstone bison has not been conducted

Objectives of the Proposed Project

- Evaluate the costs associated with:

  I. Responding to a brucellosis outbreak in Montana cattle herds under the APHIS 2010 interim rule

  II. Disease management strategies

  a) Eradicating brucellosis in bison (and elk?)
  b) Reducing brucellosis prevalence in bison (and elk?)
  c) Reducing transmission of brucellosis from bison and/or elk to cattle

  III. Developing a new domestic livestock and wildlife vaccine

Consider each of these individually:

Objectives of the Proposed Project

- Evaluate the costs associated with:

  I. Responding to a brucellosis outbreak in Montana cattle herds using the APHIS 2010 interim rule

Conceptually this is relatively straightforward.

Cattle Outbreak Costs

- Epidemiological Investigation
  - Trace back of reactors
  - Investigation of sources of infection
  - Surveillance of adjacent herds
- Herd Quarantine
  - Herd Plan
  - Feed, Handling, etc.
  - Test and removal
  - Assurance testing

Objectives of the Proposed Project

- Evaluate the costs associated with:

  II. Disease management strategies

  a) eradicating brucellosis in bison and elk
  b) reducing brucellosis prevalence in bison and elk
  c) reducing transmission of brucellosis between bison-elk-cattle

Objectives of the Proposed Project

Conceptually this is much more difficult than for Objective 1

To accurately estimate costs, we must

- Understand the relevant biology to model infection rates
- Be able to model the dynamic and stochastic nature of the various biological processes
  - Transmission
  - Vaccination
  - Test and removal
  - Separation
  - Sterilization

Objectives of the Proposed Project

- Develop estimates to parameterize the model
- Identify an approach capable of solving the dynamic, stochastic problem
- Why a dynamic model?
  - Actions today affect future variables
- Why a stochastic model?
  - The exact biological process is not known
  - Management strategy efficacy?
  - Random influences

Markov Chain Model of Infection

- Stochastic dynamic discrete model
- Used to forecast changes in brucellosis infection
- Requires transition probabilities which are the probabilities of moving from the current infection state to the state one period hence
- Transition probabilities are used to calculate the infection probabilities in any future period
- Forecasted infection rates are used to calculate expected costs

Simple Markov Chain Example of Infection: Single Species

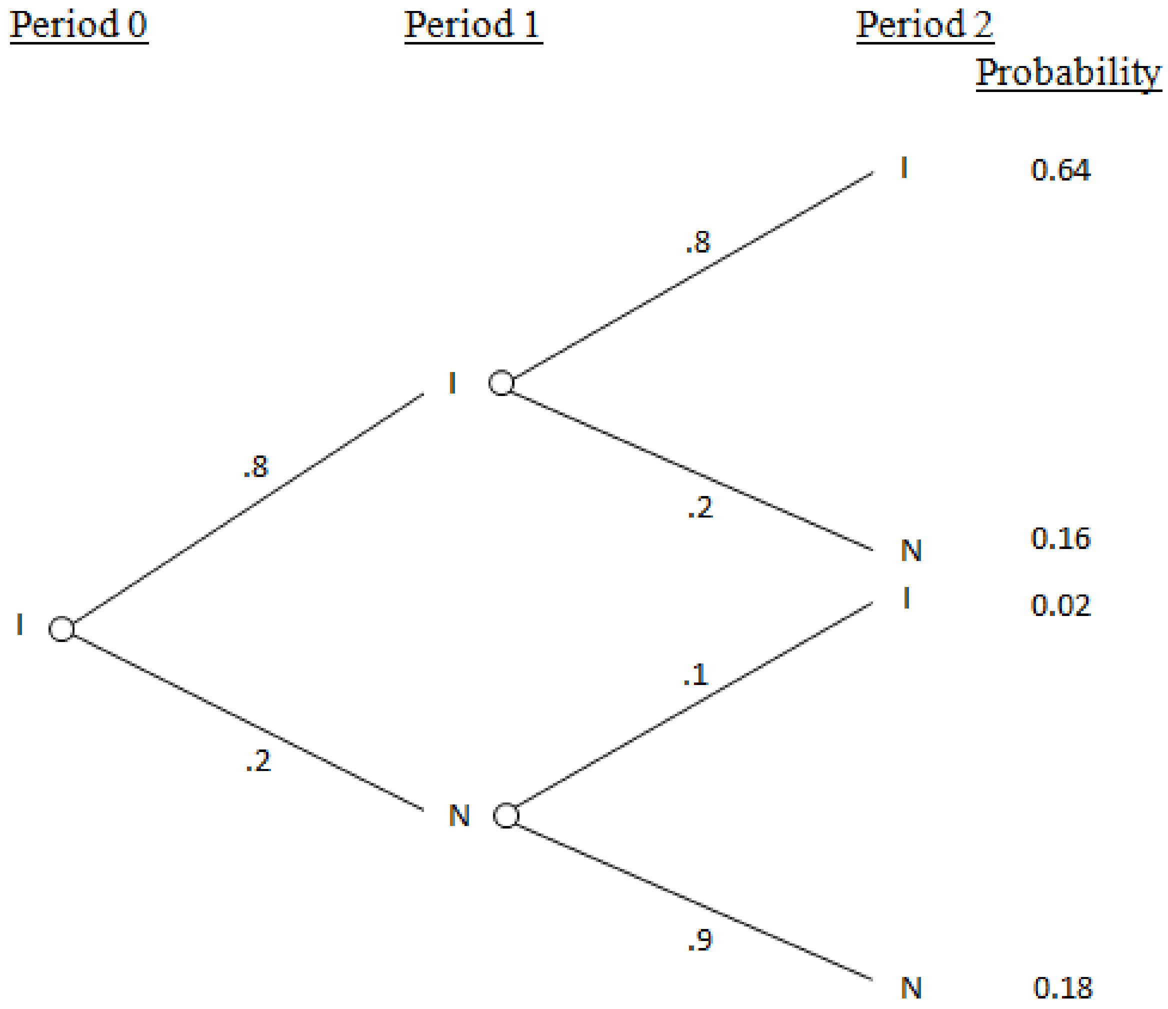
Possible States

State	Status
S_1	Infected
S_2	Not Infected

Transition Probabilities

$$P = \begin{array}{c} \\ S_1 \\ S_2 \end{array} \begin{array}{c} \begin{array}{cc} S_1 & S_2 \end{array} \\ \begin{pmatrix} .8 & .2 \\ .1 & .9 \end{pmatrix} \end{array}$$

Tree Diagram



Future Period Probabilities

$$P^2 = \begin{matrix} & S_1 & S_2 \\ S_1 & .66 & .34 \\ S_2 & .17 & .83 \end{matrix} \qquad P^8 = \begin{matrix} & S_1 & S_2 \\ S_1 & .37 & .63 \\ S_2 & .31 & .69 \end{matrix}$$

$$Steady\ State P = \left(.33\ .67 \right)$$

Infection 33%

No Infection 67%

Markov Chain Example 2

Possible States

	Status	
State	Wildlife	Cattle
S_1	Infected	Infected
S_2	Infected	Not Infected
S_3	Not Infected	Infected
S_4	Not Infected	Not Infected

Transition Probabilities

$$P = \begin{array}{c} \\ S_1 \\ S_2 \\ S_3 \\ S_4 \end{array} \begin{array}{c} \begin{array}{cccc} S_1 & S_2 & S_3 & S_4 \end{array} \\ \begin{pmatrix} .80 & .17 & .02 & .01 \\ .40 & .57 & .02 & .01 \\ .20 & .20 & .20 & .40 \\ .01 & .01 & .01 & .97 \end{pmatrix} \end{array}$$

Transition Probabilities and the Steady State

$$P^2 = \begin{pmatrix} .712 & .237 & .024 & .027 \\ .552 & .397 & .024 & .027 \\ .284 & .192 & .052 & .0472 \\ .024 & .019 & .012 & .945 \end{pmatrix} \quad P^8 = \begin{pmatrix} .594 & .258 & .023 & .126 \\ .593 & .258 & .023 & .126 \\ .349 & .157 & .019 & .476 \\ .108 & .057 & .014 & .822 \end{pmatrix} \quad P^{32} = \begin{pmatrix} .449 & .198 & .020 & .333 \\ .449 & .198 & .020 & .333 \\ .368 & .164 & .019 & .449 \\ .288 & .131 & .017 & .564 \end{pmatrix}$$

$$Steady\ State P = \left(.377\ .168\ .019\ .436\right)$$

<u>Steady State Infection Probabilities</u>

Wildlife Infected (0.377 + 0.168) = ~ 0.55

Cattle infected (0.377 +0.019) = ~0.40

Both Infected = ~0.38

Neither Infected = ~0.44

Effect of Cattle Vaccination on Transition Probabilities

$$P = \begin{array}{c} \\ S_1 \\ S_2 \\ S_3 \\ S_4 \end{array} \begin{array}{c} \begin{array}{cccc} S_1 & S_2 & S_3 & S_4 \end{array} \\ \begin{pmatrix} .80 & .17 & .02 & .01 \\ .40 & .57 & .02 & .01 \\ .20 & .20 & .20 & .40 \\ .01 & .01 & .01 & .97 \end{pmatrix} \end{array}$$

$$PR = \begin{array}{c} \\ S_1 \\ S_2 \\ S_3 \\ S_4 \end{array} \begin{array}{c} \begin{array}{cccc} S_1 & S_2 & S_3 & S_4 \end{array} \\ \begin{pmatrix} .10 & .87 & .02 & .01 \\ .05 & .92 & .02 & .01 \\ .15 & .20 & .20 & .45 \\ .01 & .01 & .01 & .97 \end{pmatrix} \end{array}$$

$$Steady\ StateP = \left(.377\ .168\ .019\ .436\right)$$

$$Steady\ StatePR = \left(.035\ .489\ .019\ .457\right)$$

Parameters

- Consider the following scenario:
  - 1000 head cattle herd
  - $10/head vaccination of cattle
  - Infection results in whole herd depopulation
  - $1,000,000 whole herd depopulation
  - Assume cattle and wildlife are initially infected (S_1)
  - Cattle disease prevalence falls from:

    0.82 (= 0.80 + 0.02) to 0.12 (= 0.10 + 0.02)

Effect of Vaccination on Costs

- **Period 1 Cost of Infection:**

	Vaccination	
	No	**Yes**
Probability of Cattle Infection	0.82	0.12
Expected Cost		
Depopulation	$820,000	$120,000
Vaccination	$0	$10,000
Total Cost	$820,000	$130,000
Difference	$690,000	

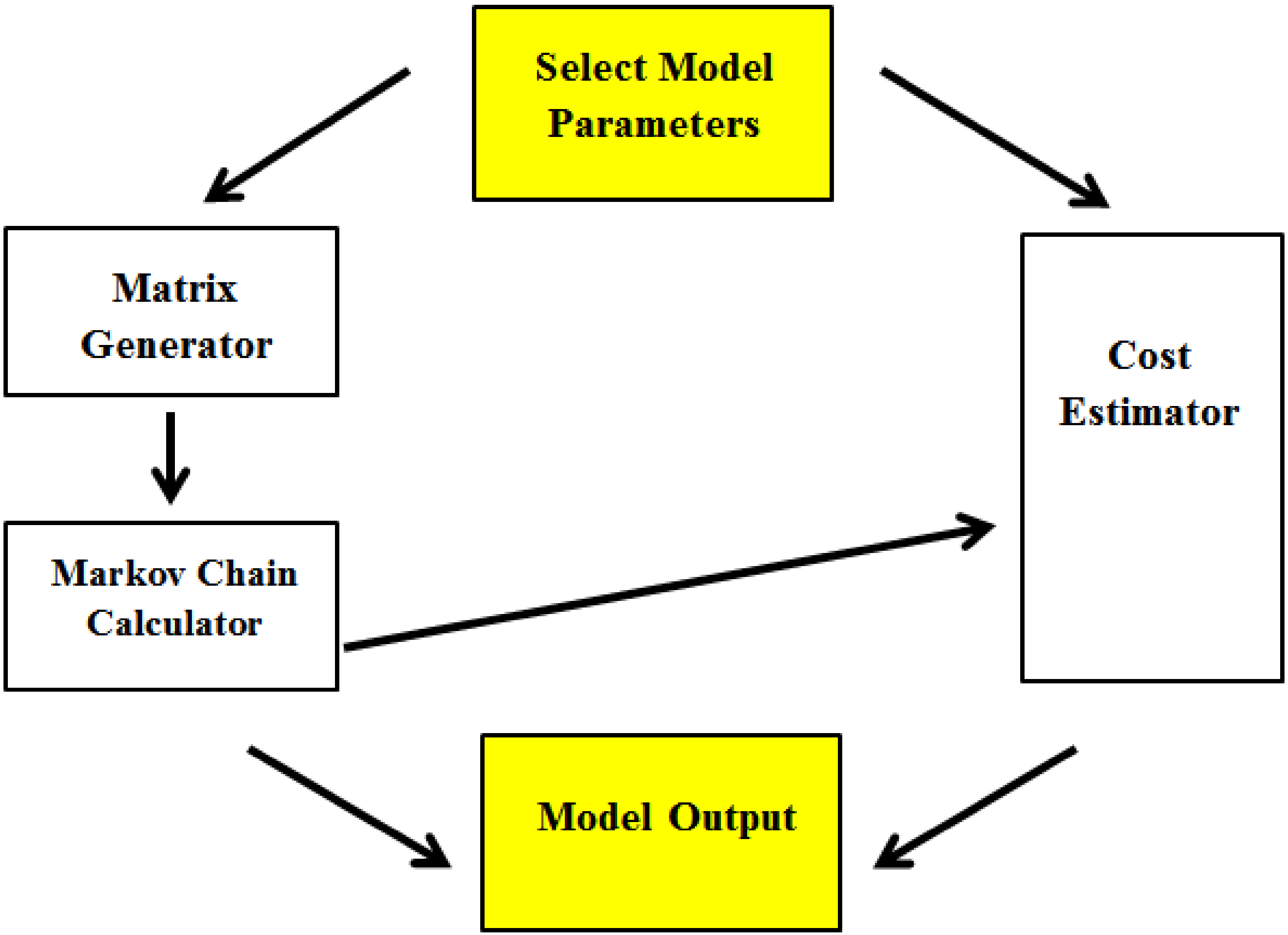
Effect of Vaccination on Costs

- Cost are also calculated for periods beyond period 1
- Present value is calculated for costs across periods for various management strategies

Model Development

- Data for transition probabilities will be acquired from:
  - Scientific literature
  - Experts in the field
  - Other industry data
- Parameter uncertainty will be dealt with through:
  - Sensitivity analysis
  - Probability distributions
- Model validation

Computerized Cost Estimator



Transition Probability Matrix Size

- Matrix size increases with:
  - Number of species
  - Number of infection rate categories
  - Number of descriptive variables
    - Population size
    - Age distribution
    - Spatial distribution
- Matrix becomes large
- Modern computer capacity sufficient
- Matrix generator

Adaptive Management

- Revise the transition probability matrix after a predetermined number of periods
- Revise the transition probability matrix after infection reaches a specified level
  - Revise the matrix
  - Incorporate directly (which substantially increases the matrix size)

Updating

- As more information becomes available model transition probabilities may be refined
- Matrix can be revised through the “Select Model Parameter” module

Objectives of the Proposed Project

- Evaluate the costs associated with:

III. Developing a new domestic livestock and wildlife vaccine

Evaluating Vaccine Costs

- Costs will be estimated for each step in the development and approval process.
- Estimates may be considerably higher or lower than the actual costs of the vaccines under consideration.
- Many vaccines are not successfully commercialized even though they are technically feasible.
- The vaccine development process will be described, cost estimates developed, and the probability of success discussed.

Vaccine Development Cost Considerations

- Vaccine efficacy; protection against:
  - Heifer infection, fetal infection, abortion
- Vaccine delivery
  - oral, remote, hand
- Dose regimen
  - booster vs. single dose
- Cross-species protection
  - Elk, bison, cattle
- Detection on serological tests
- Immunological indicators

Conclusion

- Cost estimates to be developed may aid decision makers in choosing among management strategies that result in different levels of infection over time. These include cattle outbreak costs, as well as reduction/eradication in wildlife.
- The model will be updatable as better information becomes available
- Potential and cost for development of a new vaccine will be identified and estimated

Questions?