Modelling the spread and control of African swine fever

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Emergency animal disease (EAD)

- Examples are foot-and-mouth disease (FMD), African swine fever (ASF) and lumpy skin disease (LSD).
- All of the above are exotic to Australia, but nearby.
- Potential for major economic, social, and environmental impact.
- For example, estimated damages from a large multistate outbreak of FMD in Australia is estimated at up to $A80B over ten years

Australian Government
Department of Agriculture

CSIRO

Emergency animal diseases

A field guide for Australian veterinarians

Department of Agriculture, Forestry and Fisheries, and CSIRO

https://www.outbreak.gov.au/

African swine fever (ASF)

- Contagious haemorrhagic viral disease of domestic & feral pigs (*Sus scrofa*)
- Strain of interest: Georgia 2007 genotype II
- High fever, ataxia, loss of appetite, haemorrhages, abortion, depression
- Case fatality rates 90-100%

ASF transmission

- Transmitted through direct contact, indirect contact, tick vectors.
- ASFV is resilient (pork, pork products, tissue, faeces, blood, soil).
- Feral pigs interact with carcasses.
- ASFV-infected feral pig carcasses may play an important role in transmission. Carcass decay rates will vary regionally & seasonally.

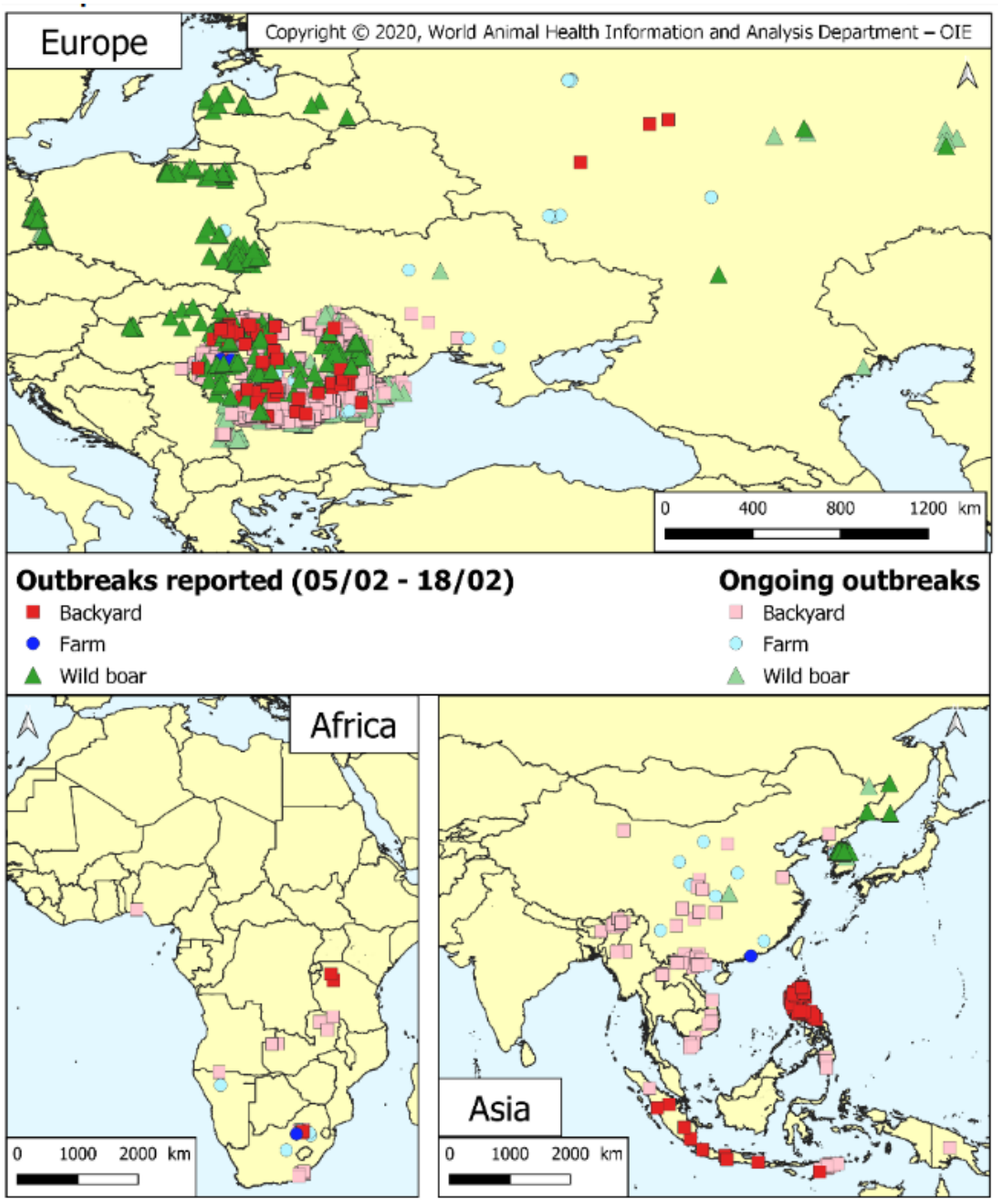


Figure 1. ASF outbreaks reported through the Early Warning system within the period. The outbreaks notified between February 05 to February 18 pointed with a higher color intensity compared to the ongoing outbreaks (lighter colors).

https://www.woah.org/en/disease/african-swine-fever/

ASF regional situation

- Not yet in Australia.
- Outbreaks recorded in neighbouring countries (Indonesia, PNG, Timor-Leste).
- Detections of ASFV DNA in pork products seized at the Australian border.
- A large multi-state outbreak poses a A$2B threat to the Australian pig industry.

ACIL Allen Consulting (2019) Economic analysis of African Swine Fever incursion into Australia. Final report to Australian Pork Limited.

What might an ASF outbreak look like in Australia?

- **Arrival pathways**: where, when, how?

- **Spread pathways**:
  - direct contacts
  - indirect contacts
  - tick-borne?
  - spillover between domestic & feral pigs

- **Detection**: where, when, how?

- **Response**:
  - policy options
  - resourcing requirements/constraints
  - post-outbreak concerns

- **Heterogeneity**:
  - production systems
  - on-farm biosecurity
  - trading patterns
  - climate
  - regionality/seasonality

Agent-based modelling

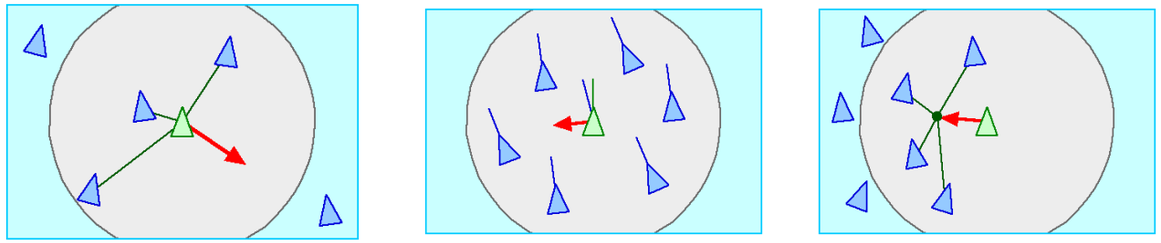
- Good at tackling complex problems in time and space
- Disaggregates a complex system into agents & an environment
- Emergent behaviour
- Captures heterogeneity, variability & uncertainty

- Disaggregating an ASF outbreak:

  Agents – herds, farms, saleyards, abattoirs

  Spread environment – direct contacts, indirect contacts, spillover between domestic & feral pigs

  Control environment – detection, movement restrictions, tracing, stamping out, resourcing



Separation | Cohesion | Alignment

Reynolds C. (1987). Flocks, herds, and schools: a distributed behavioural model. Computer Graphics 21(4)

The Australian Animal Disease Spread model (AADIS)

- AADIS is a stochastic agent-based decision support tool that simulates EADs:
  - incursion
  - spread
  - detection
  - response
  - post-outbreak management
- Developed collaboratively with the Department of Agriculture, Fisheries and Forestry.
- Test case disease was FMD.

AADIS
AUSTRALIAN ANIMAL DISEASE SPREAD MODEL

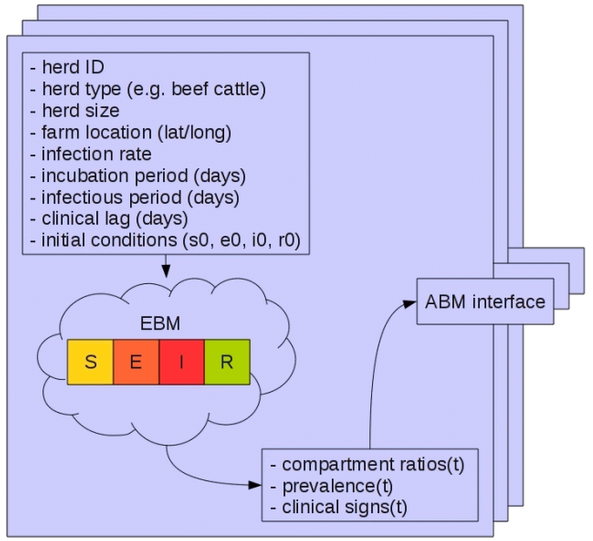
https://aadis.org.au

Australian Government
Department of Agriculture, Fisheries and Forestry

Bradhurst et al (2015). A hybrid modelling approach to simulating foot-and-mouth disease outbreaks in Australian livestock. Frontiers in Environmental Science, 3(17).

Representing the domestic pig population

- Units of interest (agents) are herds, saleyards, and abattoirs.
- A herd is group of co-mingling animals under the same production system.
- Static attributes:
  - location
  - size
  - production system
  - number of sheds
  - on-farm biosecurity measures
- Dynamic attributes
  - infection
  - disease
  - control

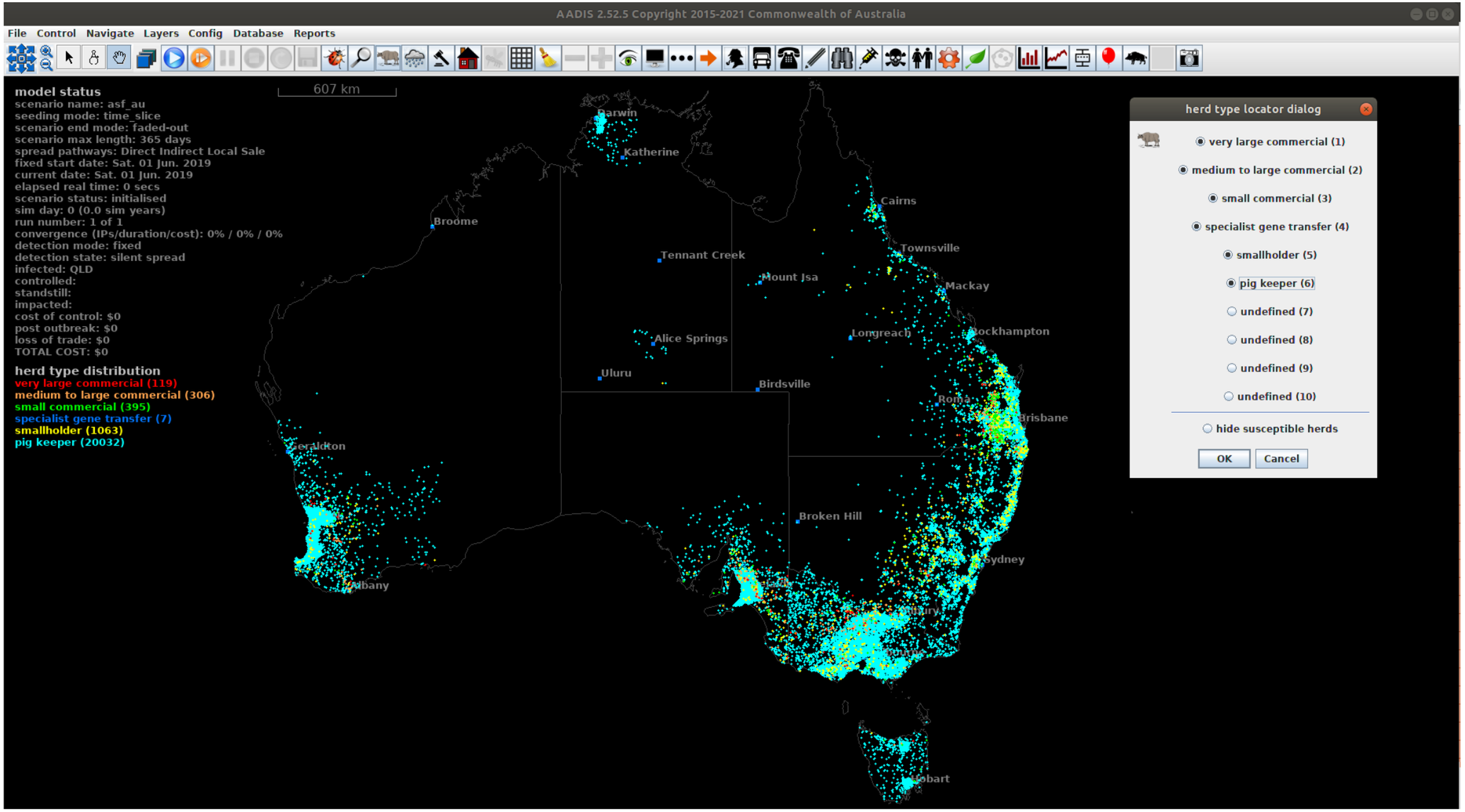


Australian domestic pig population

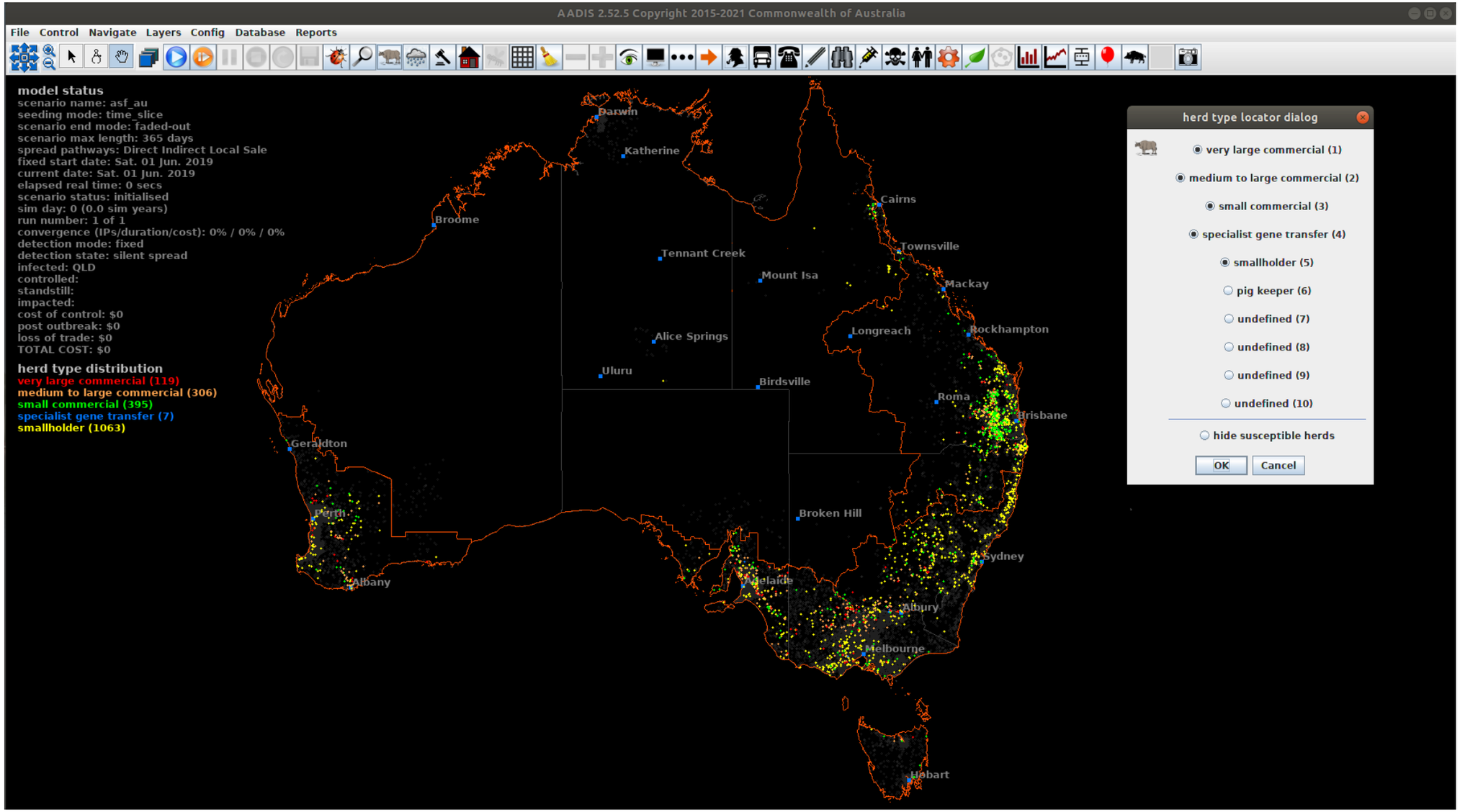
Herd type		Number of sows	Typical biosecurity	Typical movements off	Number of herds	Totals
1	Very large commercial	1000+	Routine	Multiple movements per week to export and domestic processing plants.	119	
2	Medium to large commercial	151-1000	Moderate	Weekly pig movements to domestic and export processing plants.	306	**825**
3	Specialist gene transfer	N/A	Routine	Regular movements of semen.	6	
4	Small commercial	51-150	Low	Regular pig movements to domestic processing plants.	394	
5	Smallholder	1 - 50	Low	Occasional movements to domestic abattoirs.	1064	**1064**
6	Pig keeper	1 - 50	Very low	Infrequent unrecorded movements.	20,029	**20,029**
						21,918

Bradhurst R., Garner G., Richards K., Willis S., Taha H., Sellens E., Naing L., Cowled B., Roche S. (2022). Modelling post-border spread and control of African swine fever on a national scale. Technical report for Biosecurity Innovation Program Project 182021, prepared for the Department of Agriculture, Fisheries and Forestry. University of Melbourne.

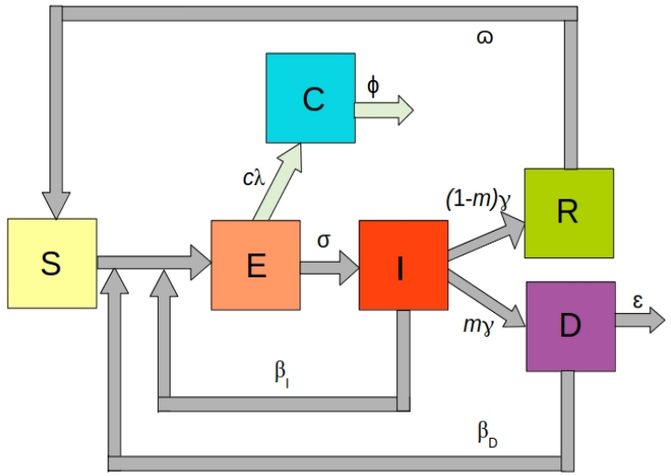
Distribution of pig herds



Distribution of pig herds (excluding pig keepers)

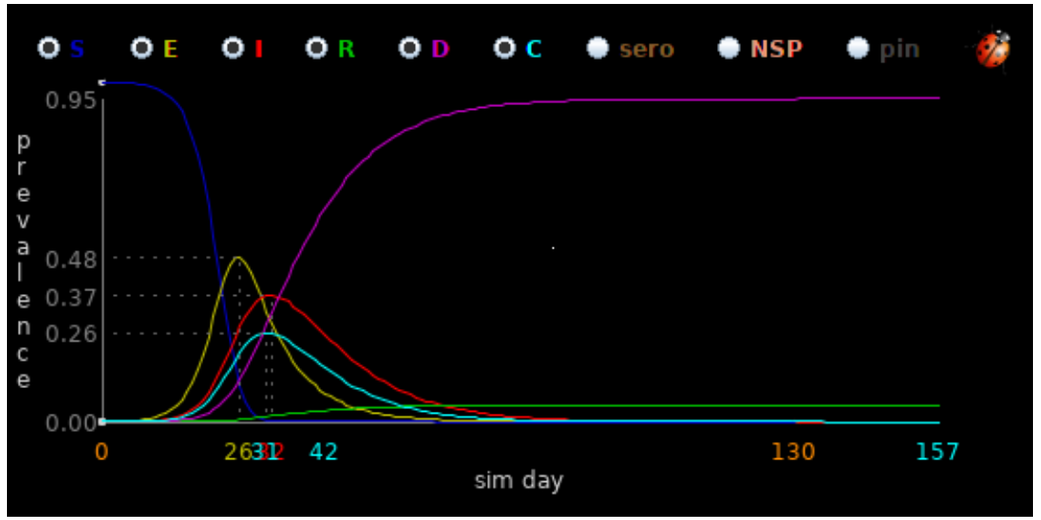


Representing the spread of ASF within a herd

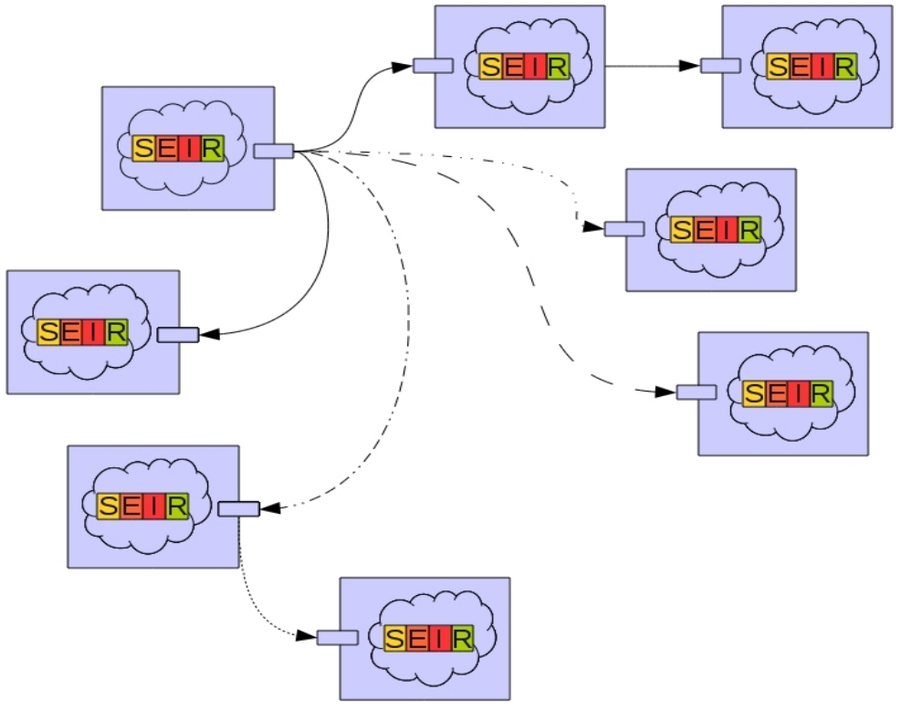


- Each herd agent has an embedded equation-based model (EBM) that takes into account
  - virus strain
  - production system
  - number of production units (sheds) within the herd

$$\frac{dS}{dt} = \frac{-\beta_I IS - \beta_D DS}{N} + \omega R$$
$$\frac{dE}{dt} = \frac{\beta_I IS + \beta_D DS}{N} - \sigma E$$
$$\frac{dI}{dt} = \sigma E - \gamma I$$
$$\frac{dR}{dt} = (1-m)\gamma I - \omega R$$
$$\frac{dD}{dt} = m\gamma I - \varepsilon D$$
$$\frac{dC}{dt} = c\lambda E - \phi C$$



Representing the spread of ASF between domestic pig farms



- ASF transmission can occur via stochastic pathways
  - ➢ direct contacts (stochastic or via replay of NLIS-logged movements of livestock)
  - ➢ indirect contacts (estimated by herd type)
  - ➢ local spread between neighbours
- The infectious pressure inside a herd (modelled by the embedded EBM) influences the likelihood of transmission to other herds

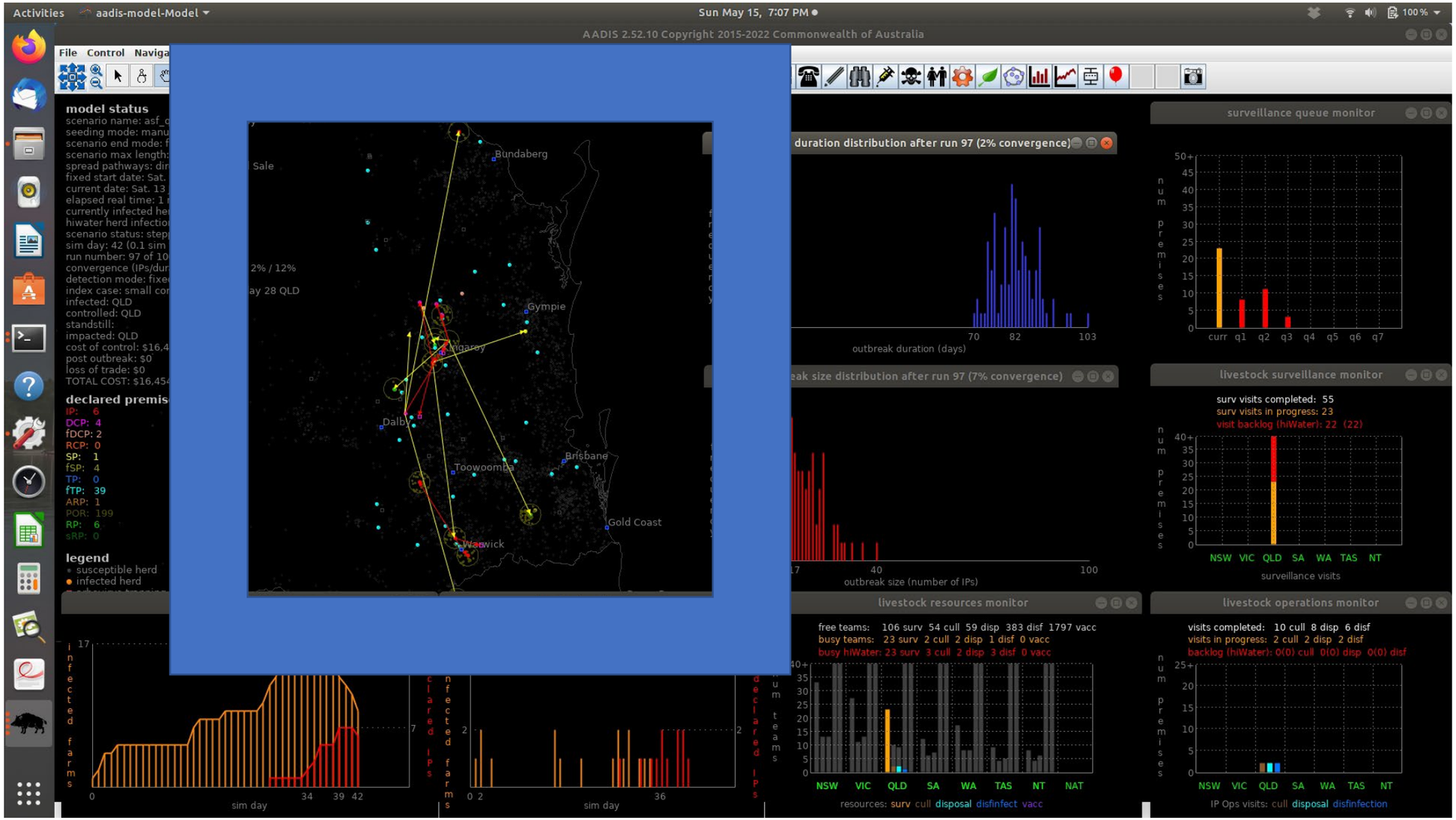
Bradhurst R., Garner G., Roche S., Iglesias R., Kung N., Robinson B., Willis S., Cozens M., Richards K., Cowled B., Oberin M., Tharle C., Firestone S., Stevenson M. (2021). Modelling the spread and control of African swine fever in domestic and feral pigs. Technical report for CEBRA project 20121501, prepared for the Department of Agriculture, Water and the Environment. University of Melbourne.

Modelling the control of ASF in domestic pig farms

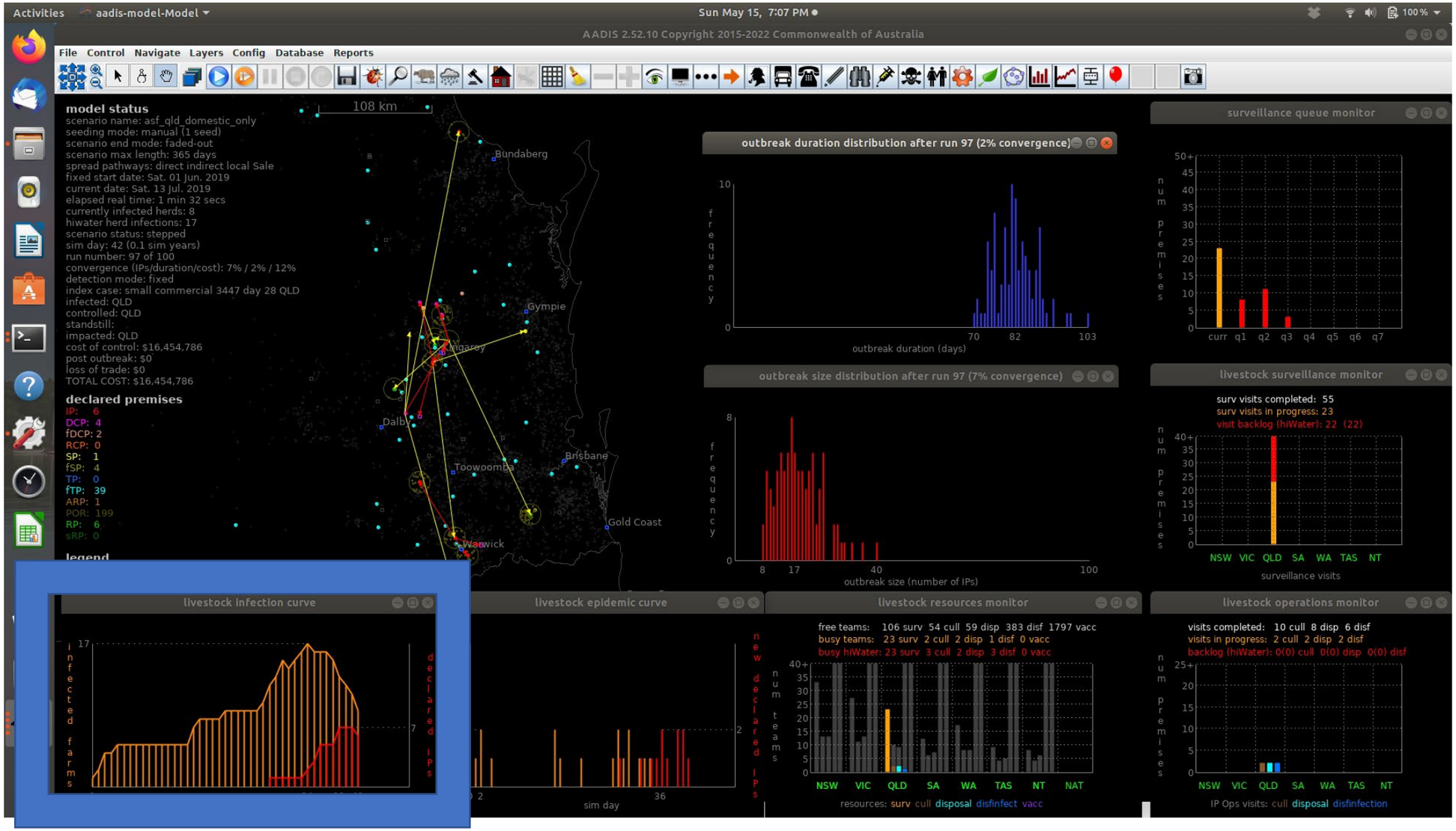
- Movement restrictions in declared areas
- Tracing (direct/indirect, forwards/backwards)
- Surveillance
- Stamping out (removal, disposal, disinfection)
- Vaccination (disabled but available if a vaccine becomes available)
- All control actions are resource-constrained and costed
- Post-outbreak surveillance
- Response imperfections are included (e.g., insufficient resources, false positive reporting of clinical signs, tracing inefficiencies, quarantine leaks)

Animal Health Australia (2021). Response strategy African swine fever (version 5.1). Australian Veterinary Emergency Plan (AUSVETPLAN), Edition 5, Canberra, ACT.

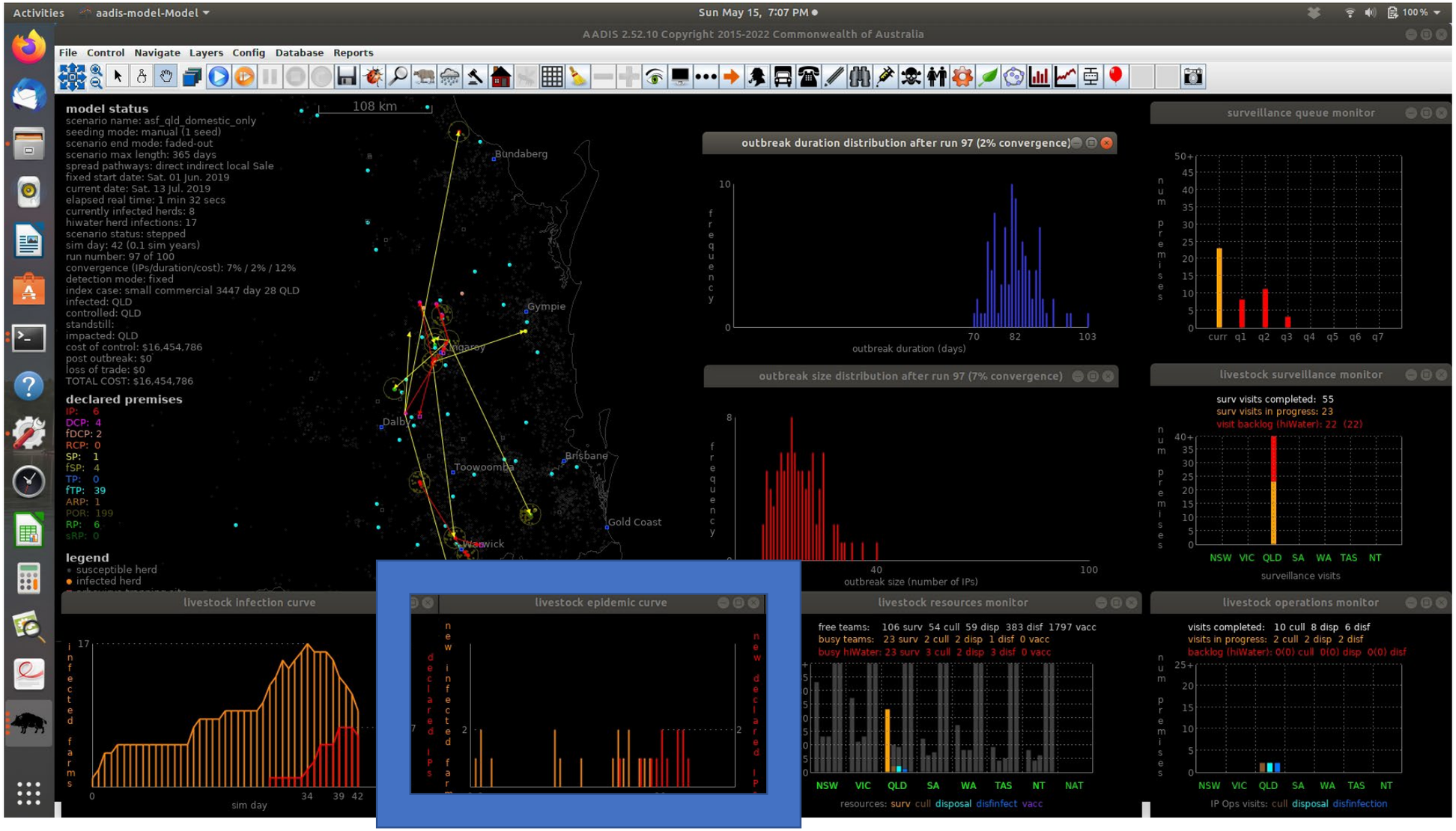
AADIS – outbreak visualisation (infection network)



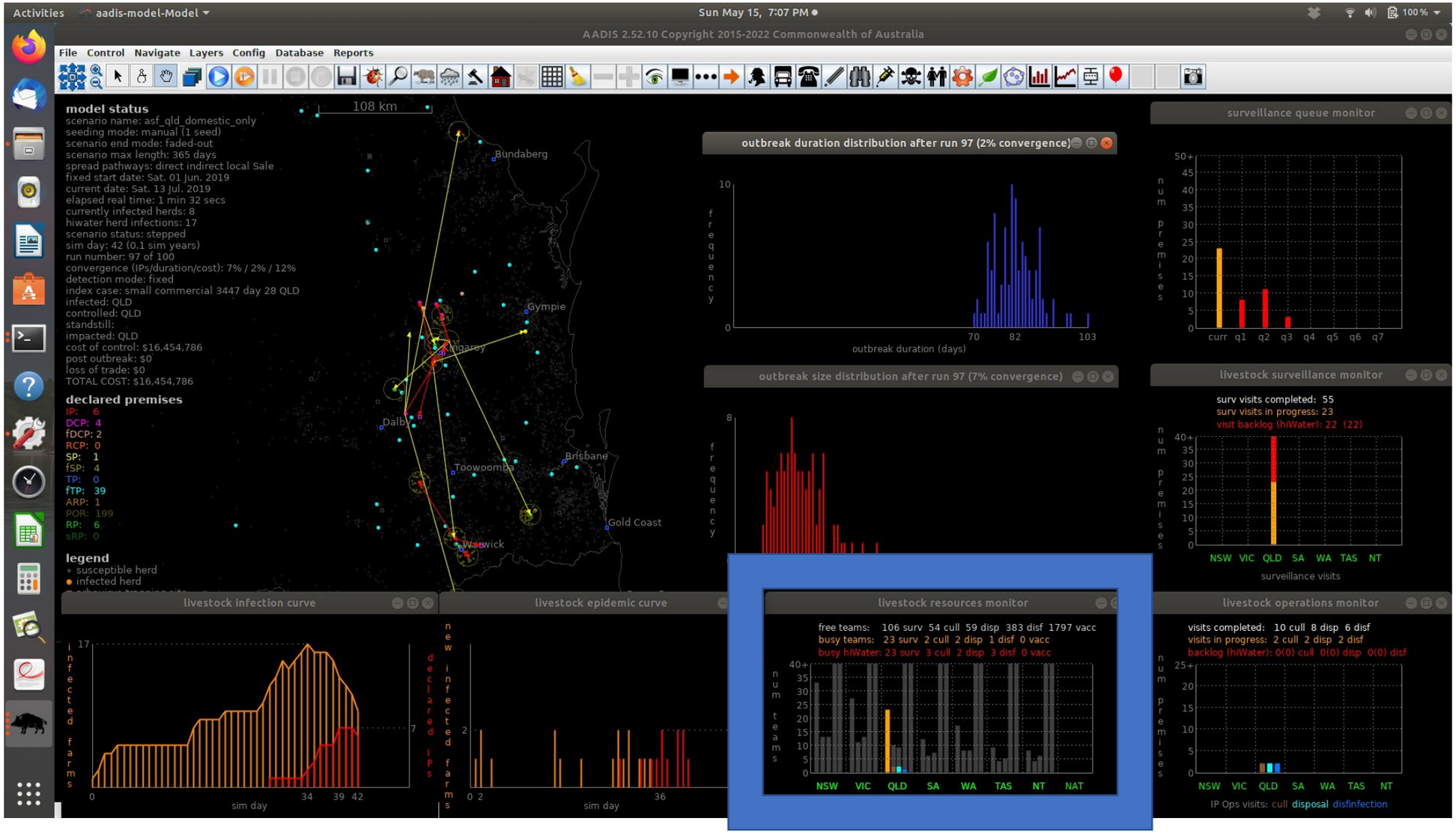
AADIS – infection curve (the unknown vs the known)



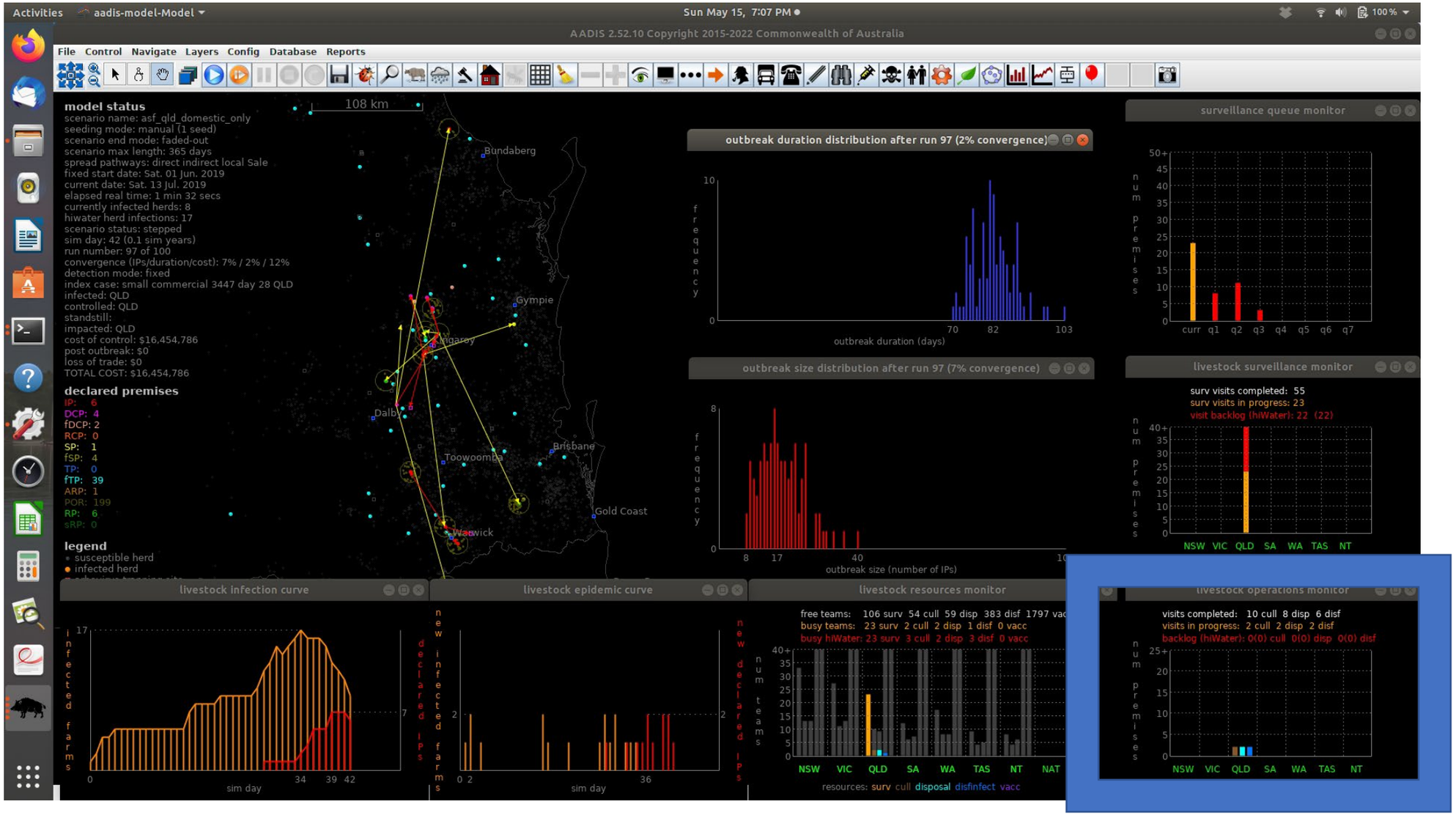
AADIS – epi curve



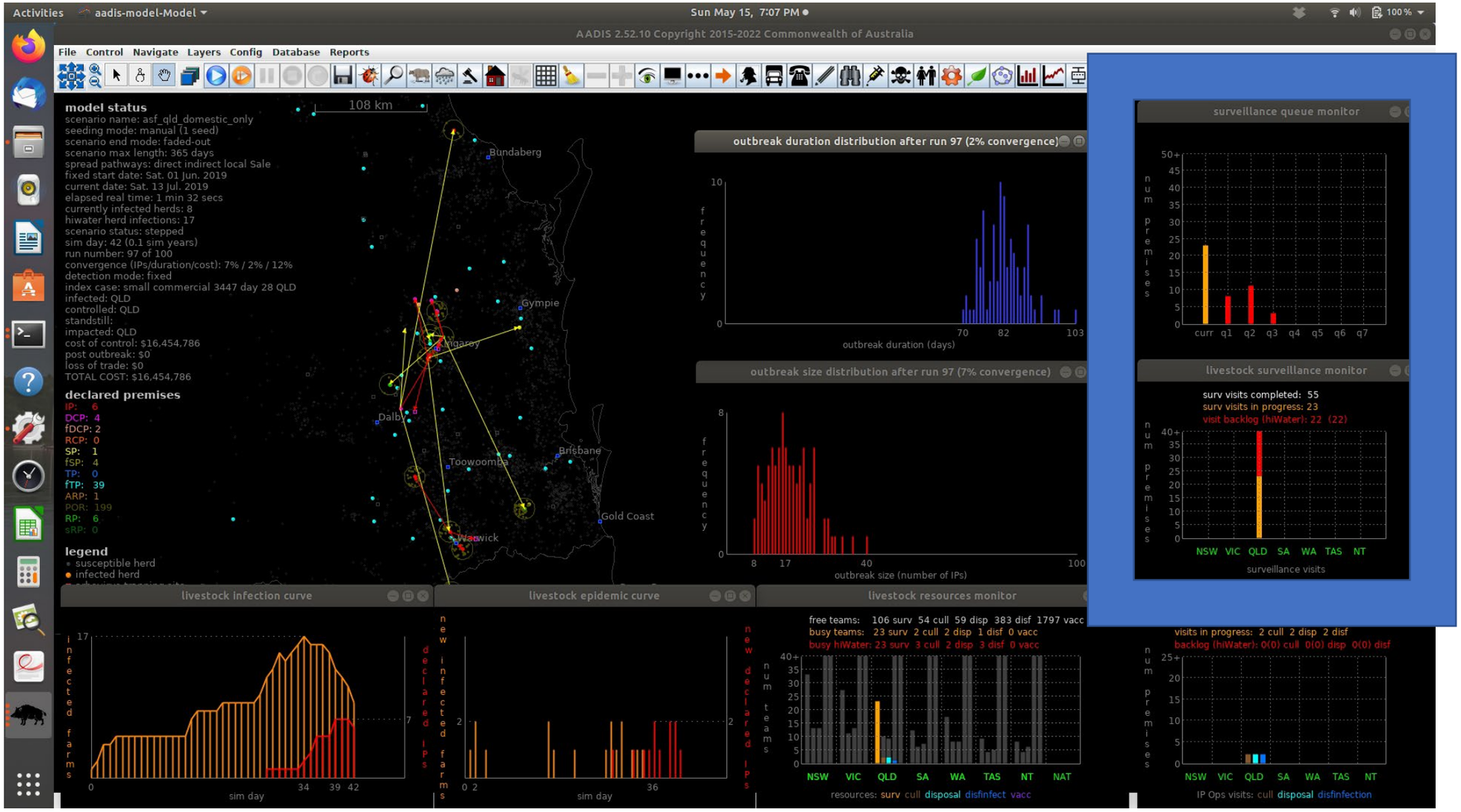
AADIS – resource pools



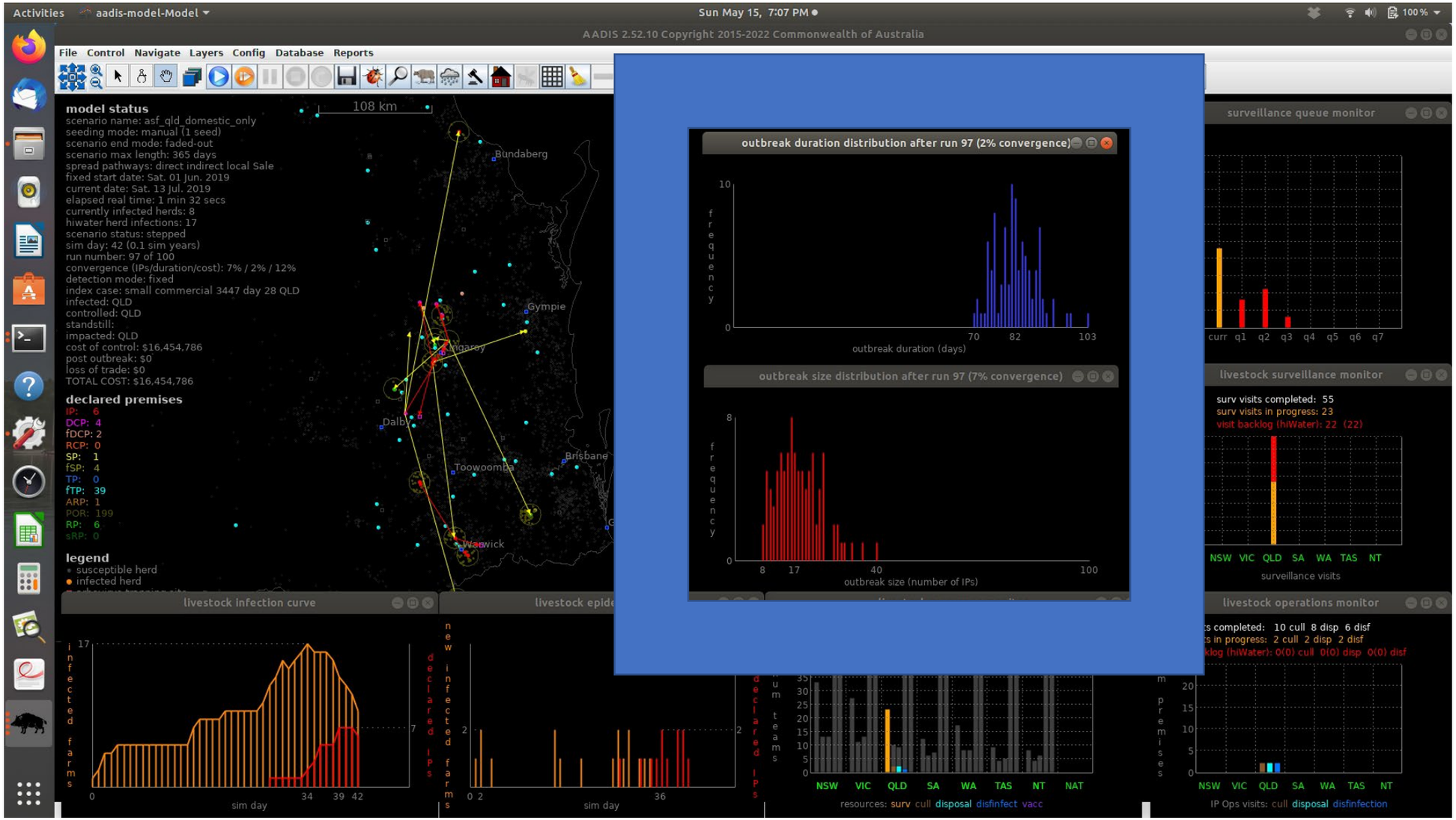
AADIS – IP operations



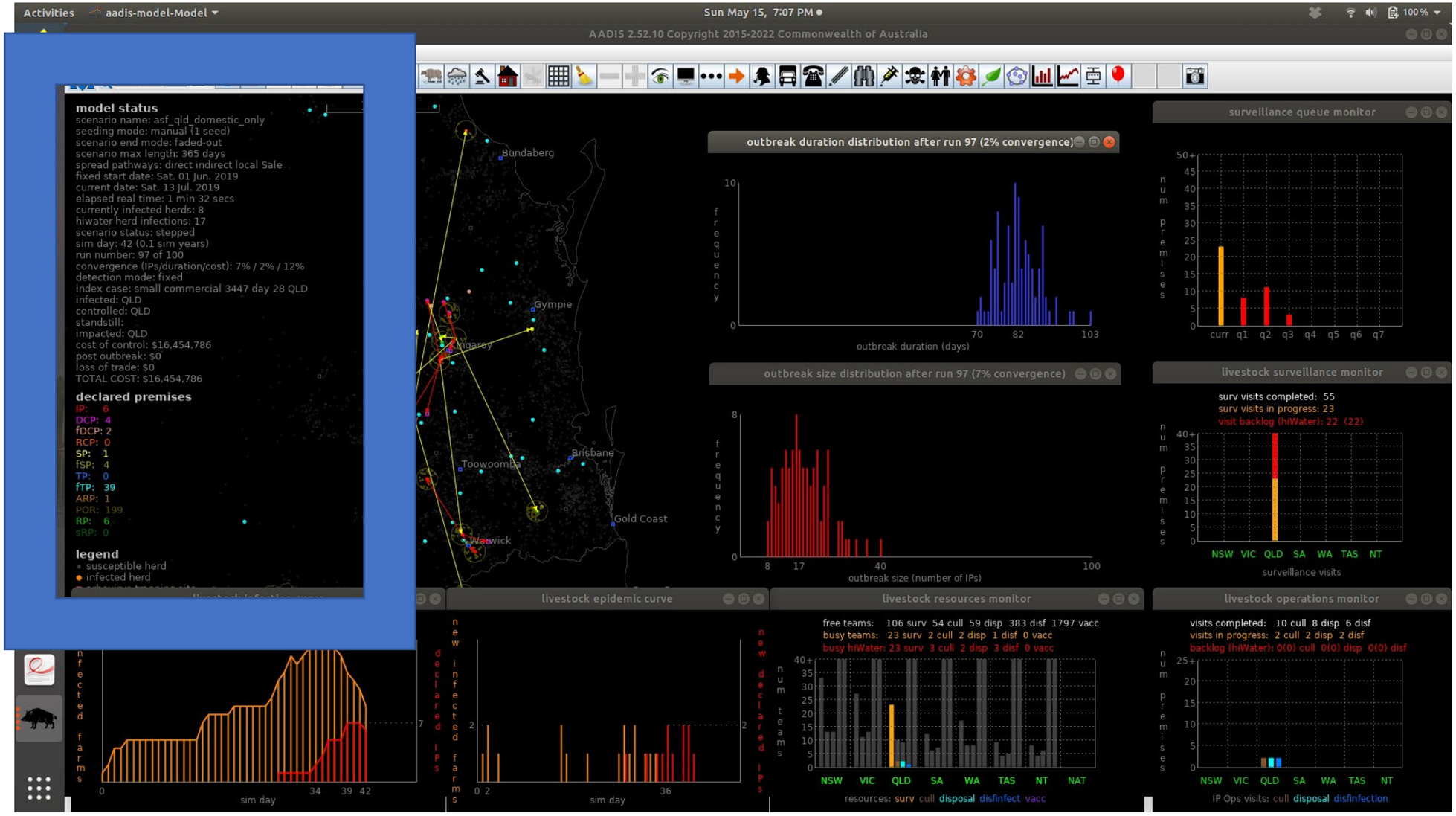
AADIS - surveillance



AADIS – example outcome distributions



AADIS – simulation status



How might AADIS inform animal health policy?

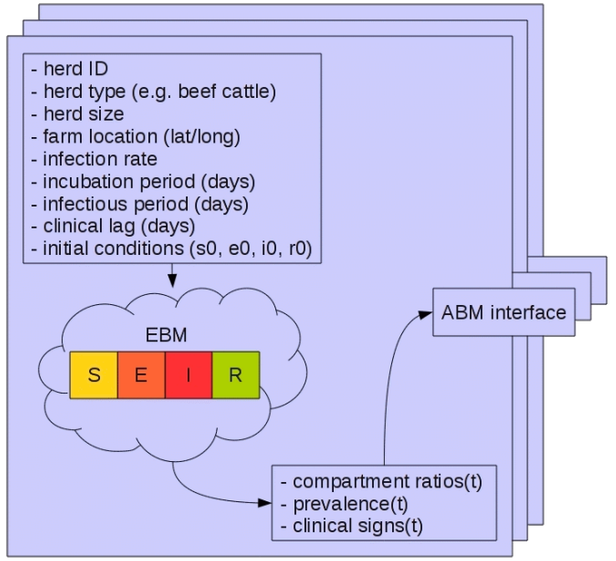
- Experiments are conducted via user controls (like a flight simulator).

- Specific epi, operational and policy questions are easily posed, e.g.,
  - how will a winter incursion differ from a summer incursion?
  - what are the consequences of late detection?
  - what resources will be needed for a big outbreak?
  - are the controlled areas the right size?
  - will suppressive ring vaccination help?
  - will there be enough vaccine?
  - should we only vaccinate certain species/herd types?
  - what is the impact of illegal movements?

- Test case was EAD in livestock…..now what about feral pigs?

Representing the feral pig population

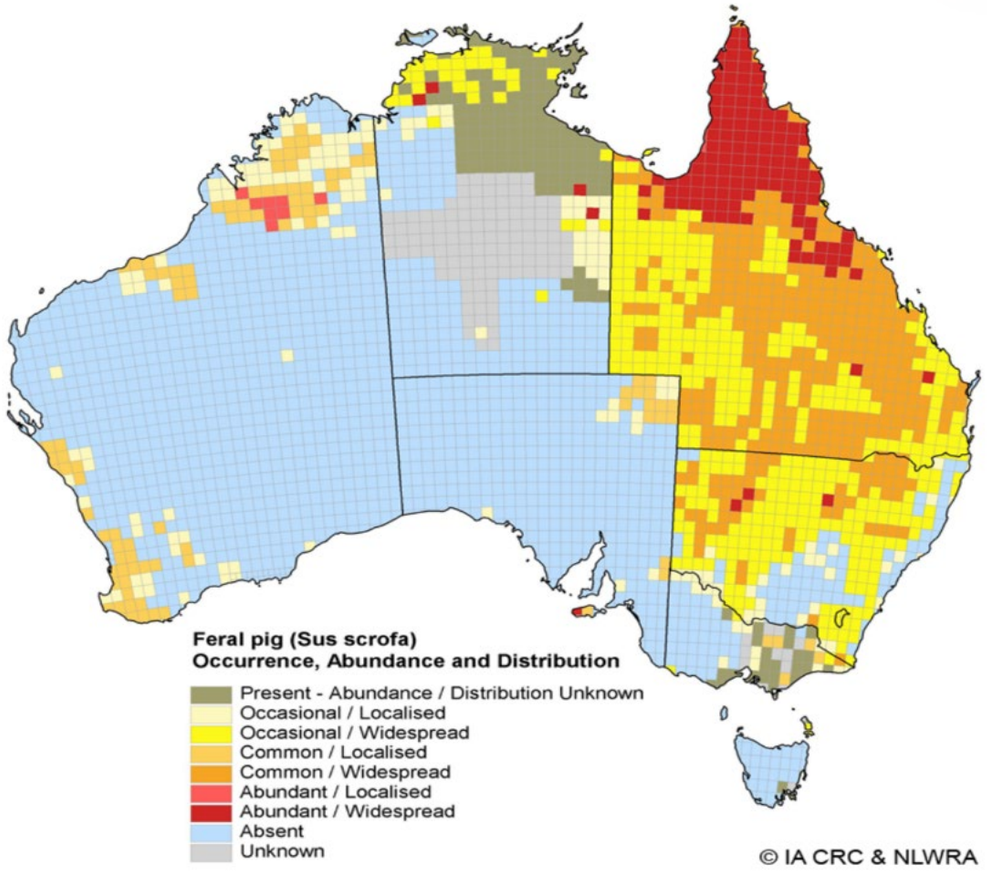
- Units of interest (agents) are sounders
- Familial group of co-mingling animals
- Static attributes
  - home range (varies regionally & seasonally)
  - size (varies regionally & seasonally)
- Dynamic attributes
  - infection
  - disease
  - control



Representing feral pig distribution & abundance

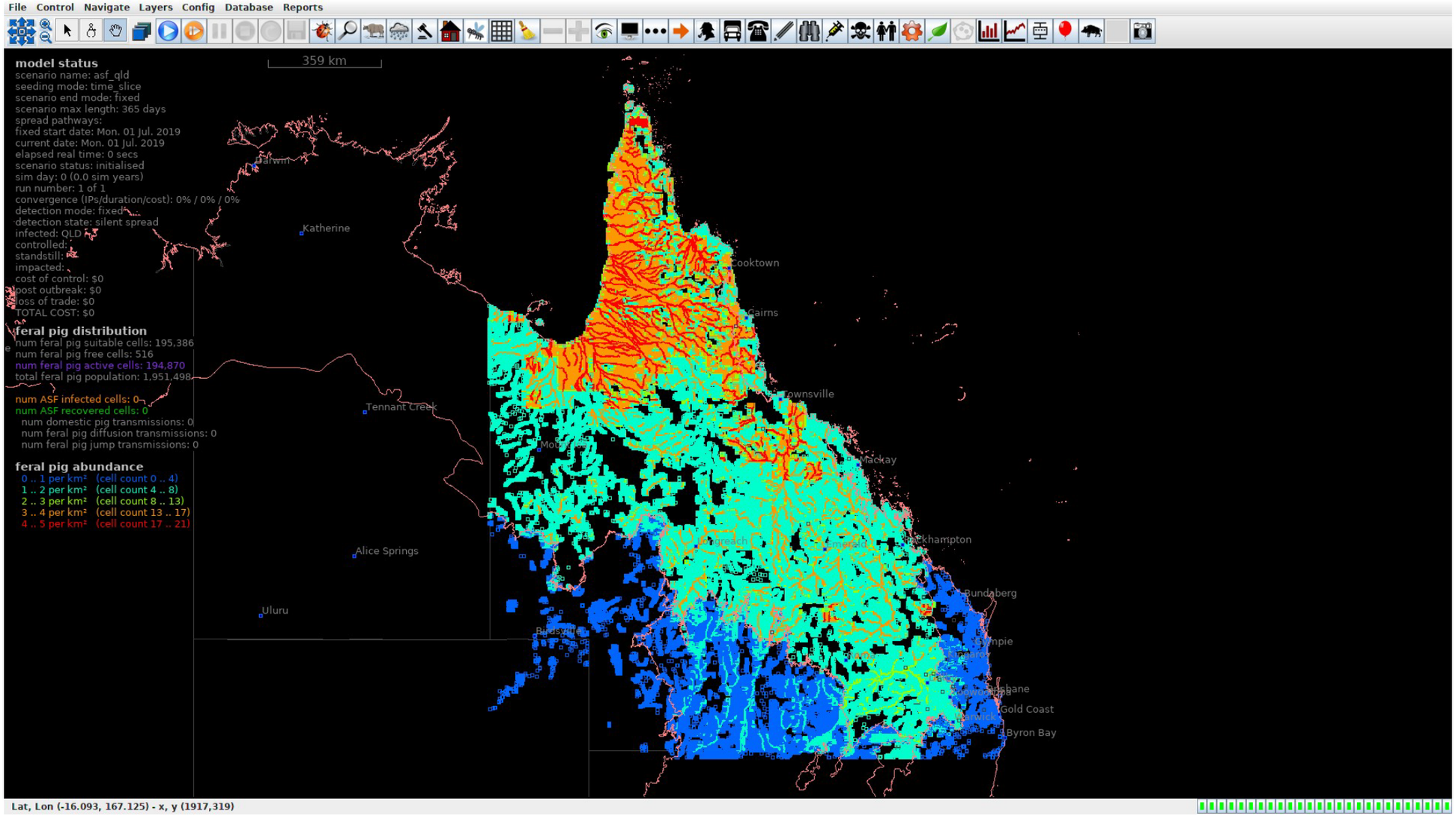
- Starting point was the 2008 West data

- Augmented with
  - other national & regional studies
  - habitat suitability data
  - permanent water data
  - land use data
  - vegetation data



West, P. (2008). Assessing Invasive Animals in Australia 2008. Invasive Animals Cooperative Research Centre, Australian Government National Land & Water Resources Audit.

Representing feral pig distribution & abundance in Qld



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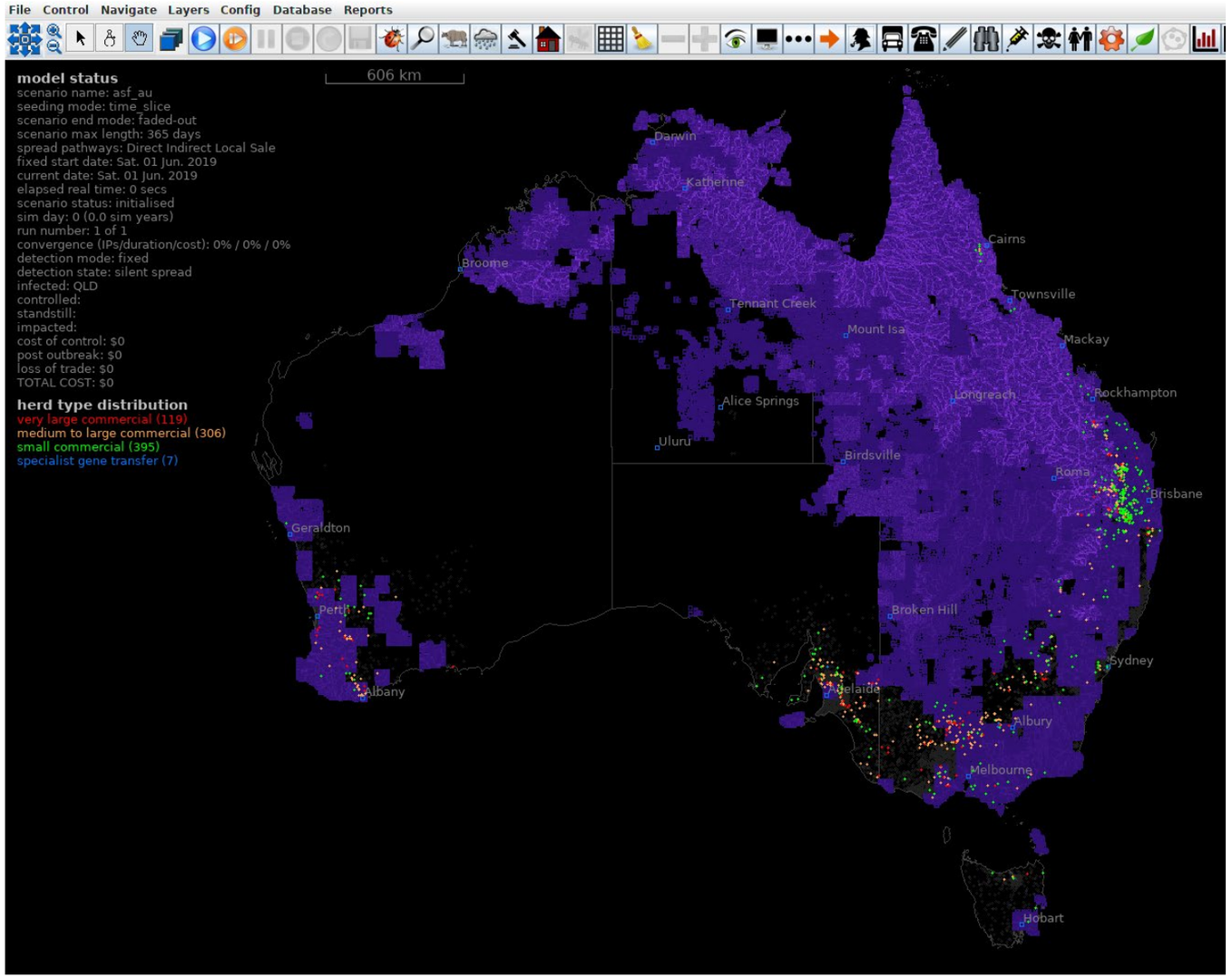
Representing the feral pig population nationally



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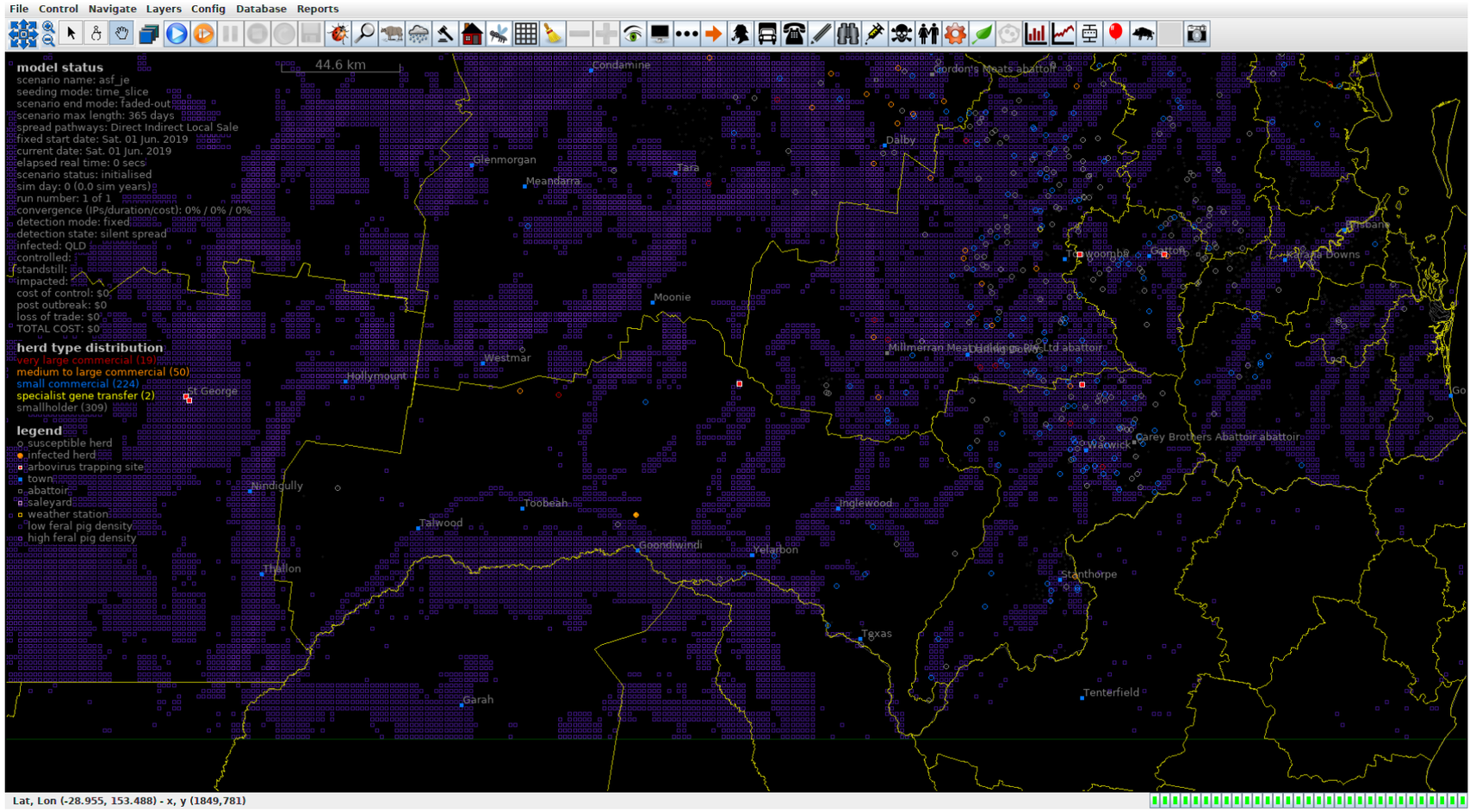
South East Qld domestic + feral pig population



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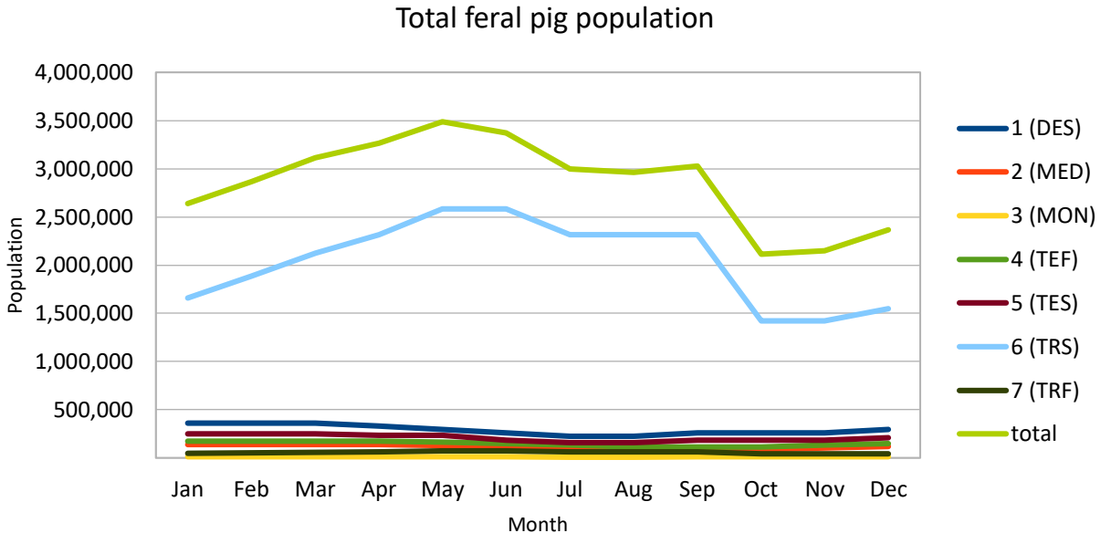
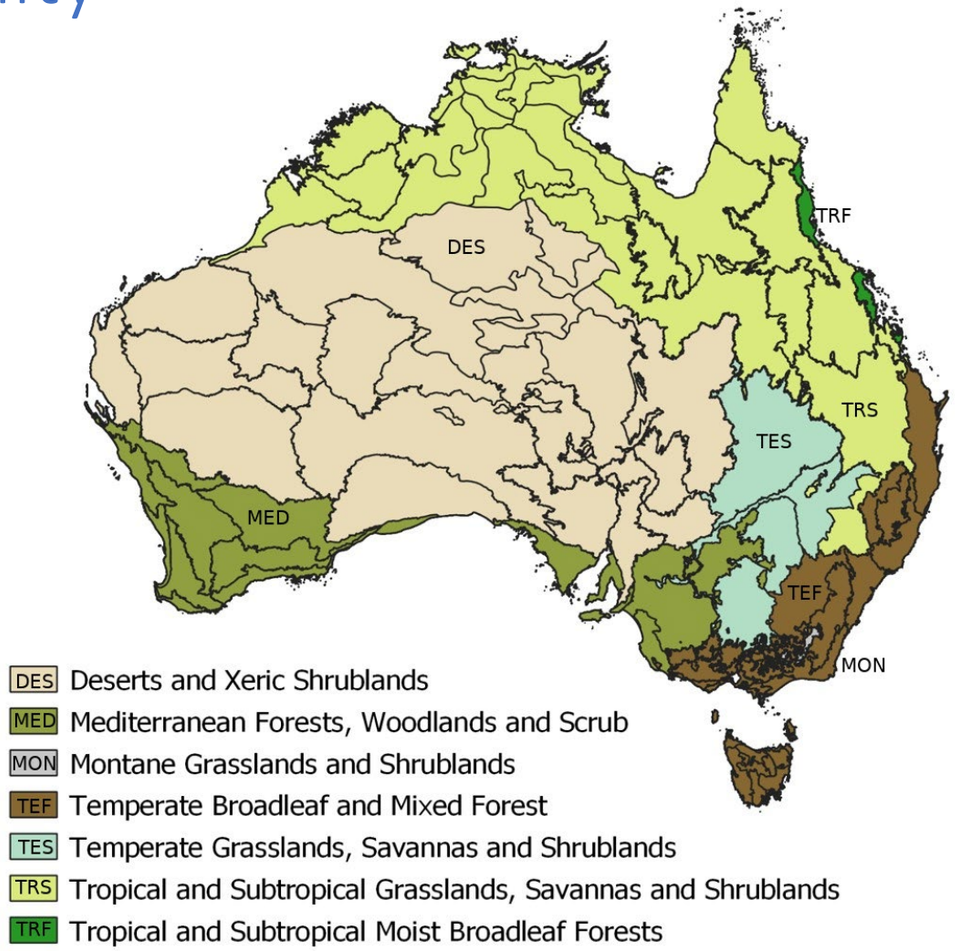
Incorporating regionality & seasonality

- 7 eco-regions
- Monthly raster data layers of feral pig distribution & abundance informed by regional studies on feral pig population dynamics
- Sounder size and home range allowed to vary by region and by season





Department of Sustainability, Environment, Water, Population and Communities, 2021

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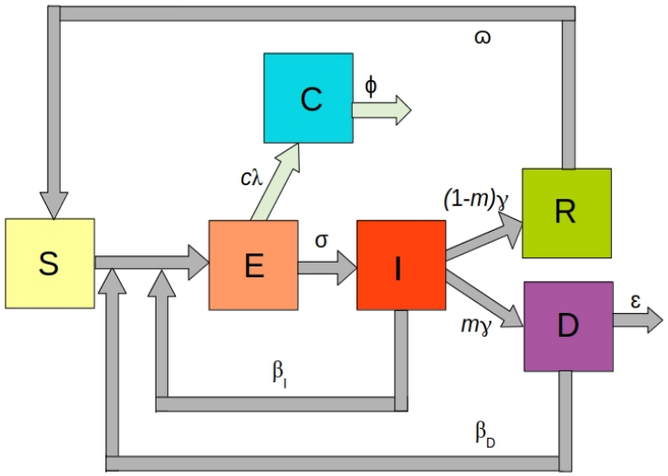
Representing the spread of disease within a feral pig sounder



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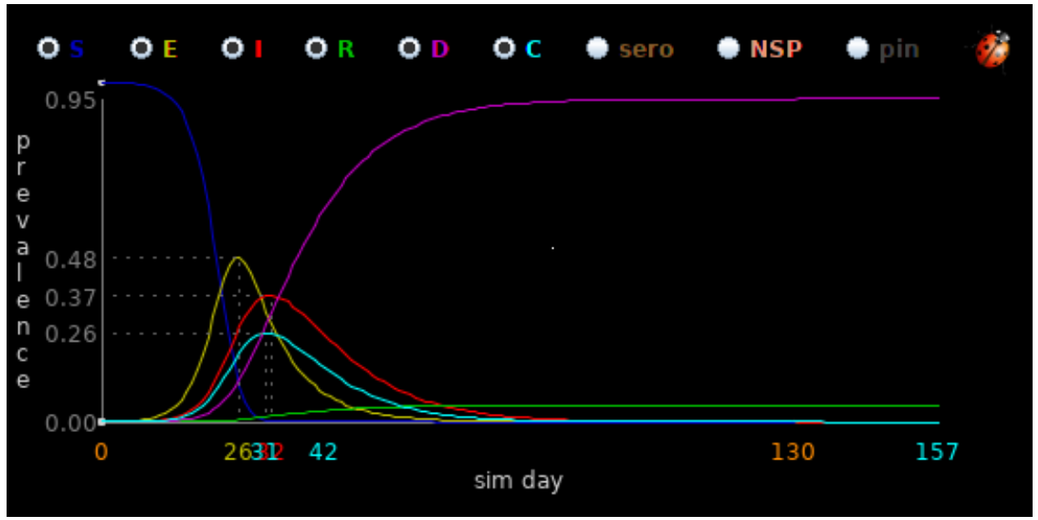
$$\frac{dE}{dt} = \frac{\beta_I IS + \beta_D DS}{N} - \sigma E$$
$$\frac{dI}{dt} = \sigma E - \gamma I$$
$$\frac{dR}{dt} = (1-m)\gamma I - \omega R$$
$$\frac{dD}{dt} = m\gamma I - \varepsilon D$$
$$\frac{dC}{dt} = c\lambda E - \phi C$$

- Similar ODE system as used for domestic herds
- Members of a sounder are assumed to mix homogeneously
- The D compartment (driven by the mortality rate *m* and the carcass decay rate ε) may contribute to transmission



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Modelling the spread of ASF between sounders

- Spread between feral pig sounders is driven by estimated contact rates (which can vary regionally and seasonally)

- Likelihood of spread is informed by:
  - feral pig density, home range, activity
  - infectious prevalence
  - carcass decay rates
  - seasonal and regional variability

Bradhurst R., Garner G., Roche S., Iglesias R., Kung N., Robinson B., Willis S., Cozens M., Richards K., Cowled B., Oberin M., Tharle C., Firestone S., Stevenson M. (2021). Modelling the spread and control of African swine fever in domestic and feral pigs. Technical report for CEBRA project 20121501, prepared for the Department of Agriculture, Water and the Environment. University of Melbourne.

Modelling the spread of ASF between domestic and feral pigs

- Spread between feral and domestic pigs is driven by estimated contact rates (which can vary regionally and seasonally).

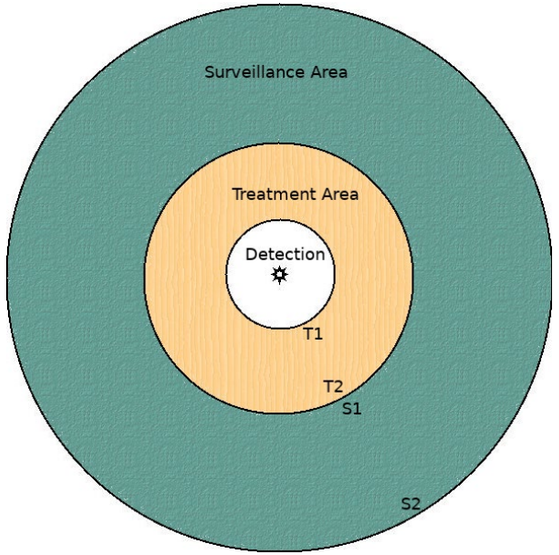
- Likelihood of spread is informed by:
  - feral pig density, home range, activity
  - infectious prevalence
  - carcass decay rates
  - locations of domestic pig farms
  - on-farm biosecurity measures
  - seasonal and regional variability

Bradhurst R., Garner G., Roche S., Iglesias R., Kung N., Robinson B., Willis S., Cozens M., Richards K., Cowled B., Oberin M., Tharle C., Firestone S., Stevenson M. (2021). Modelling the spread and control of African swine fever in domestic and feral pigs. Technical report for CEBRA project 20121501, prepared for the Department of Agriculture, Water and the Environment. University of Melbourne.

Modelling feral pig surveillance and control

Model users can experiment with:

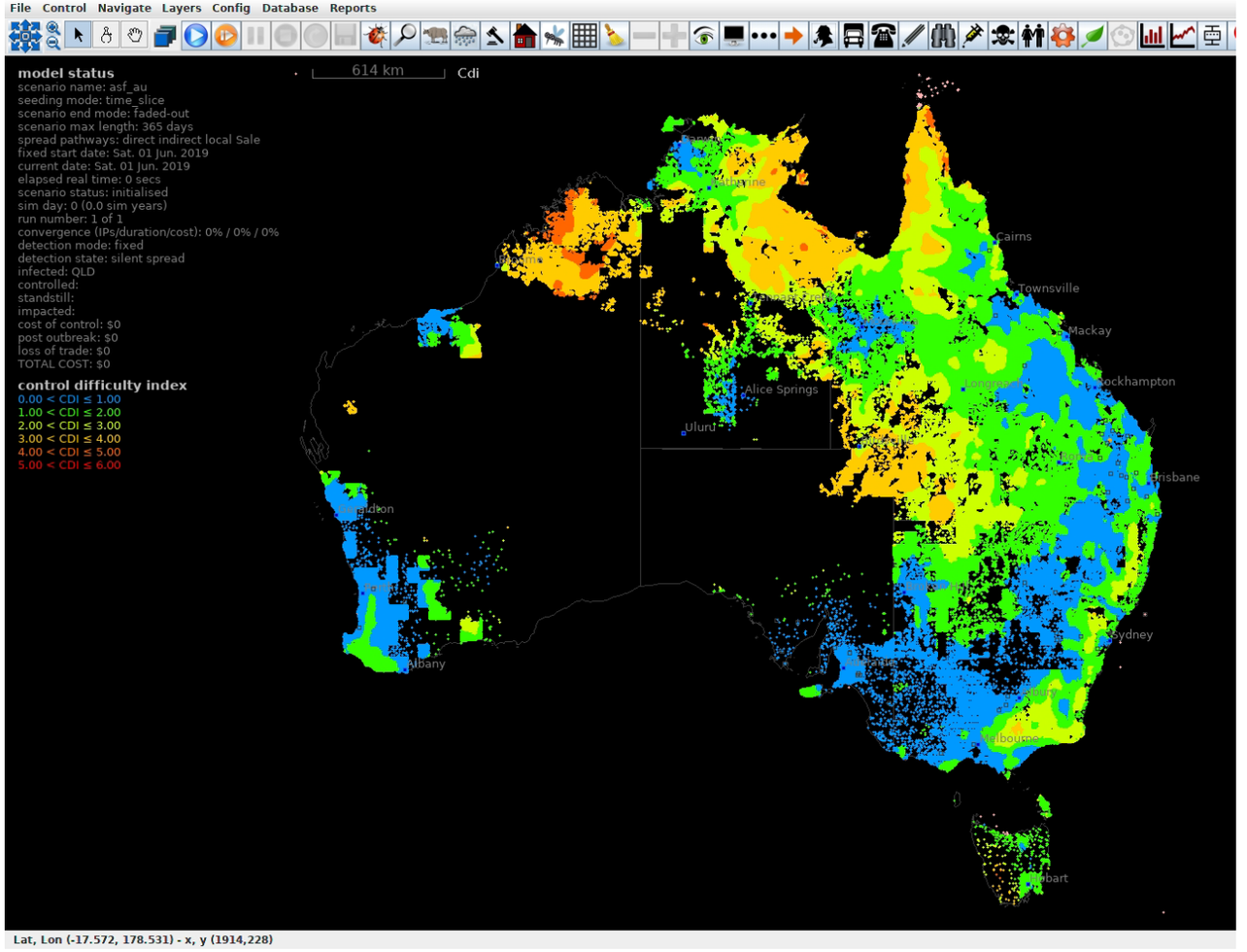
- background general surveillance
- active delimiting surveillance
- population thinning
- carcass detection and removal
- post-control surveillance



Animal Health Committee (2020). African swine fever (ASF) feral pig task group report 2020.

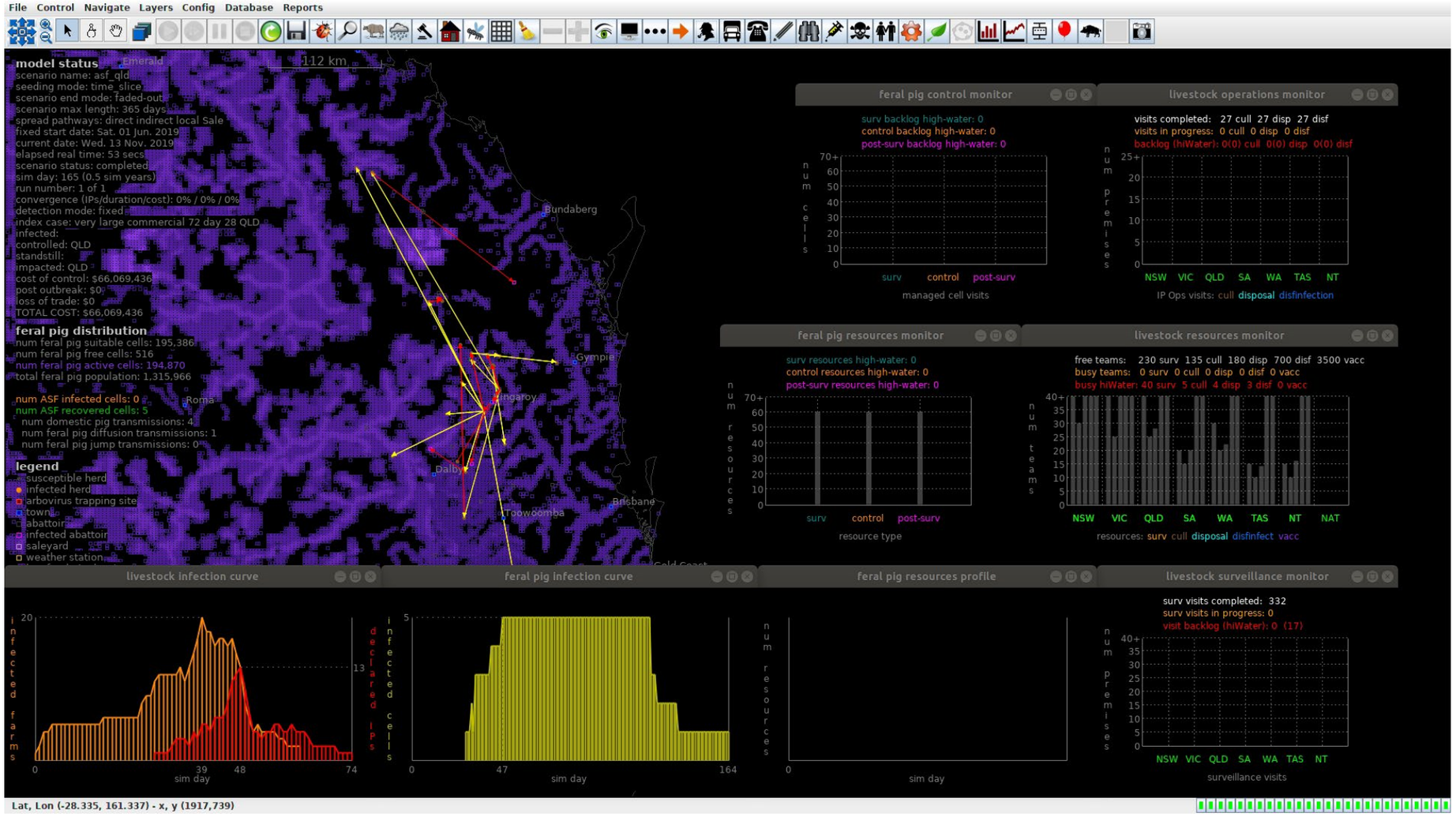
Control difficulty index (CDI)

- Relative difficulty in enacting control
- Incorporates
  - terrain ruggedness
  - proximity to transport networks
  - land use
  - remoteness
- Influences control efficacy

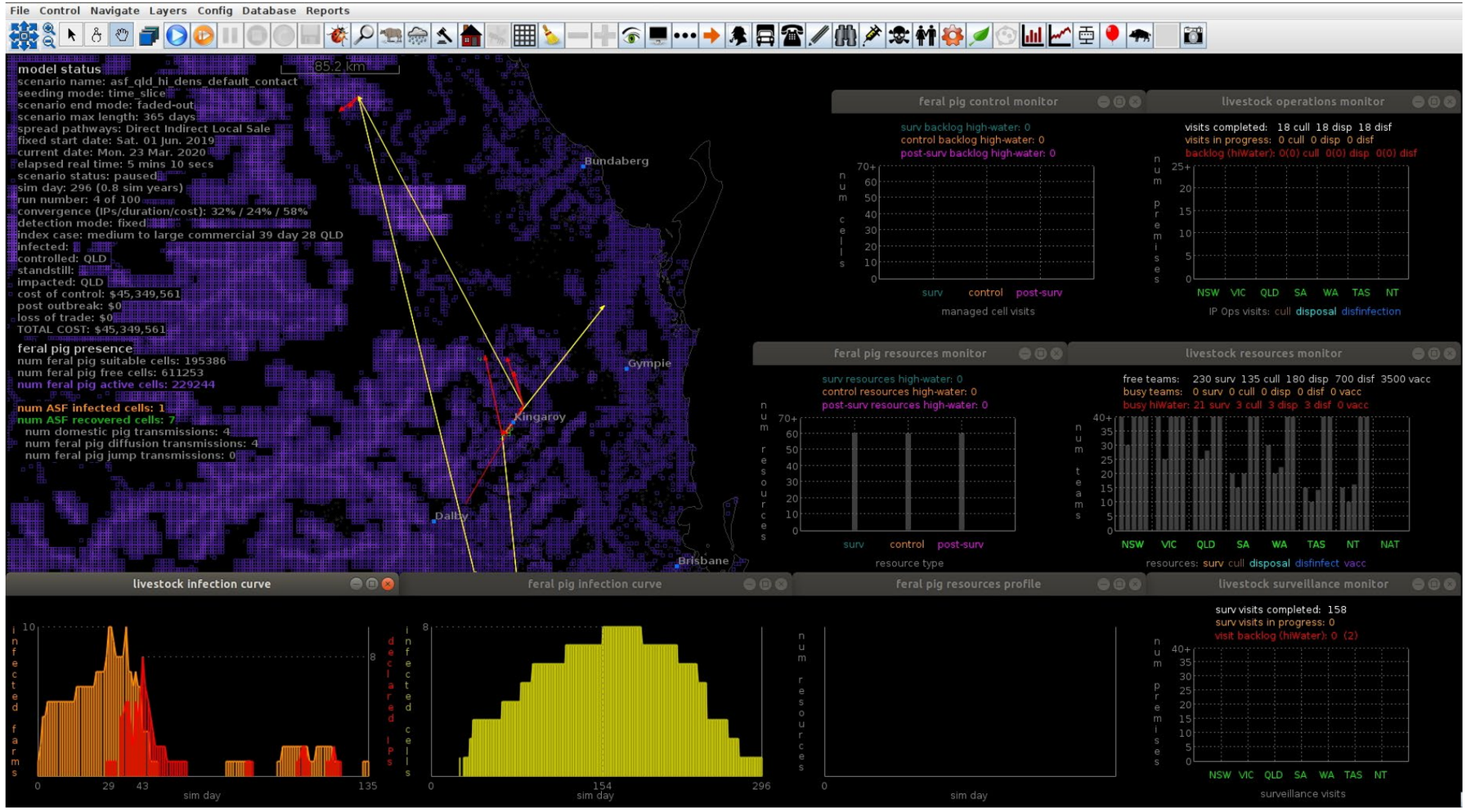


Hoskins, A. & Perry, J. (2020). Feral Pig Control Difficulty Index. v2. CSIRO. Data Collection. https://doi.org/10.25919/5ec45bbb43ee4

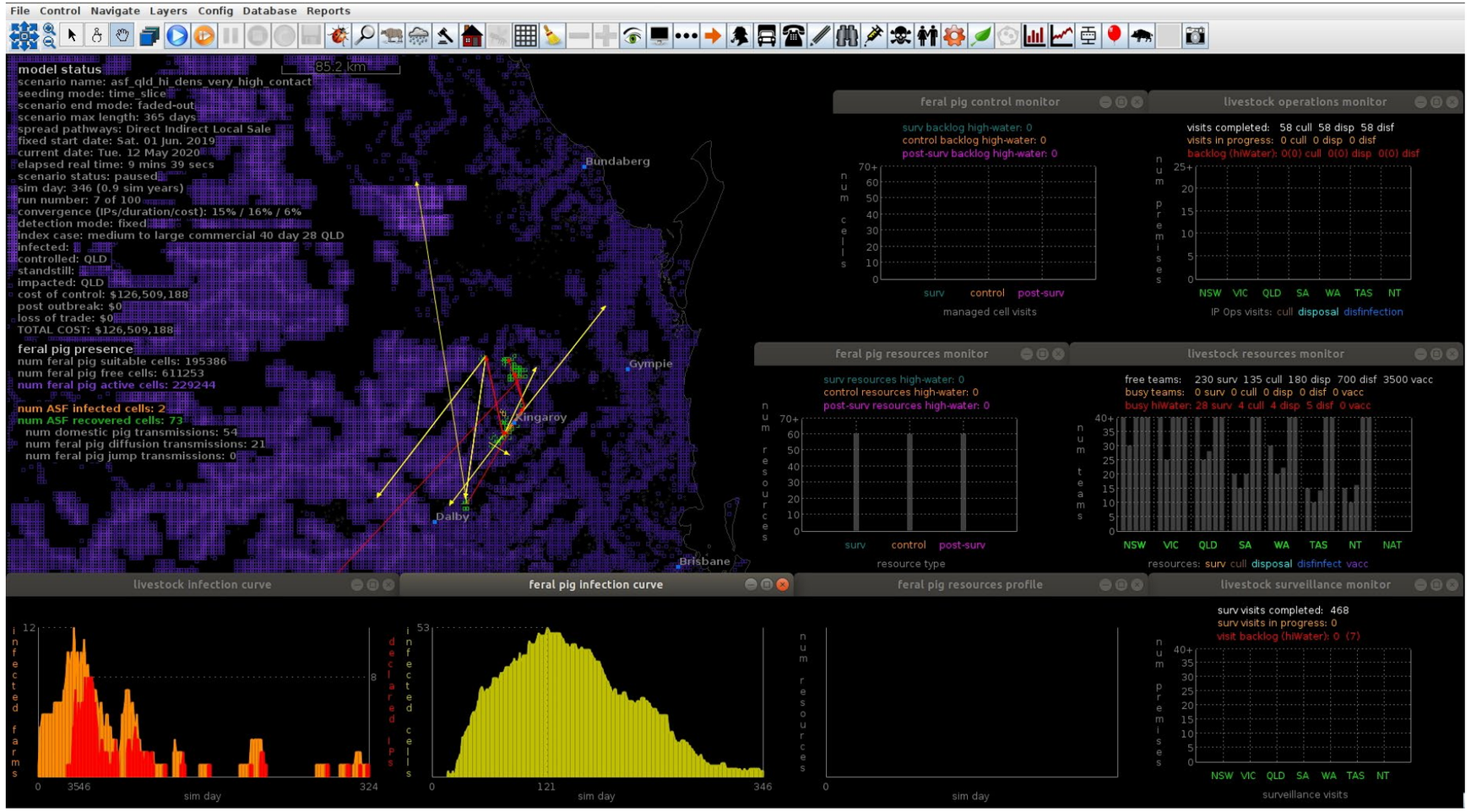
AADIS-ASF-QLD with default feral pig population



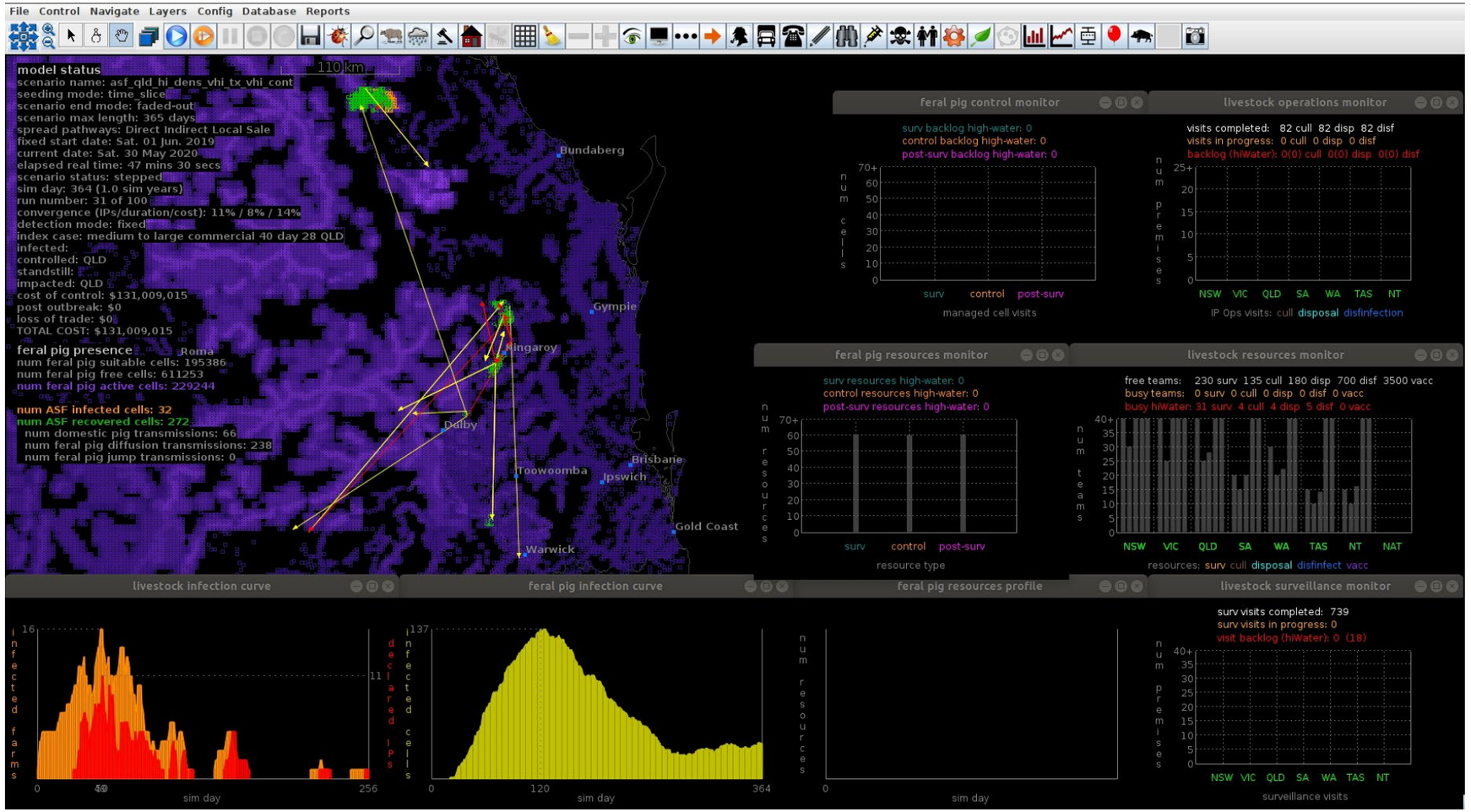
AADIS-ASF-QLD with high feral pig population



AADIS-ASF-QLD with high feral pig population & high inter-sounder contact rates



AADIS-ASF-QLD with high feral pig population and high inter-sounder & spillover contact rates



AADIS-ASF Emergent behaviour

- **Non-commercial premises** (smallholders & pig keepers):
  - low biosecurity -> more prone to spillover to/from feral pigs
  - low stock numbers & limited movements off -> tendency to fade out
  - generally play a limited role in outbreaks

- **Commercial premises:**
  - better biosecurity -> less prone to spillover to/from feral pigs
  - limited transmission to/from non-commercial premises
  - indirect transmission a significant outbreak driver (consistent with Europe)
  - outbreaks likely to be controlled within 6 months (per model assumptions)

Bradhurst R., Garner G., Roche S., Iglesias R., Kung N., Robinson B., Willis S., Cozens M., Richards K., Cowled B., Oberin M., Tharle C., Firestone S., Stevenson M. (2021). Modelling the spread and control of African swine fever in domestic and feral pigs. Technical report for CEBRA project 20121501, prepared for the Department of Agriculture, Water and the Environment. University of Melbourne.

AADIS-ASF Emergent behaviour

- **Feral pigs:**
  - spread velocity varies but averages about 20km/year (consistent with Europe)
  - spillover depends on feral pig population density and on-farm biosecurity
  - outbreak size and duration depends on feral pig density, proximity to domestic pigs, contact rates, and carcass decay rates
  - outbreaks likely to fade-out within 12 months if controlled in the domestic population

- **Heterogeneity:**
  - larger and longer outbreaks in colder months/regions (slower carcass decay, increased ASFV viability, increased feral pig activity)
  - **regional and seasonal variability is a key driver of outbreak characteristics**

Bradhurst R., Garner G., Roche S., Iglesias R., Kung N., Robinson B., Willis S., Cozens M., Richards K., Cowled B., Oberin M., Tharle C., Firestone S., Stevenson M. (2021). Modelling the spread and control of African swine fever in domestic and feral pigs. Technical report for CEBRA project 20121501, prepared for the Department of Agriculture, Water and the Environment. University of Melbourne.

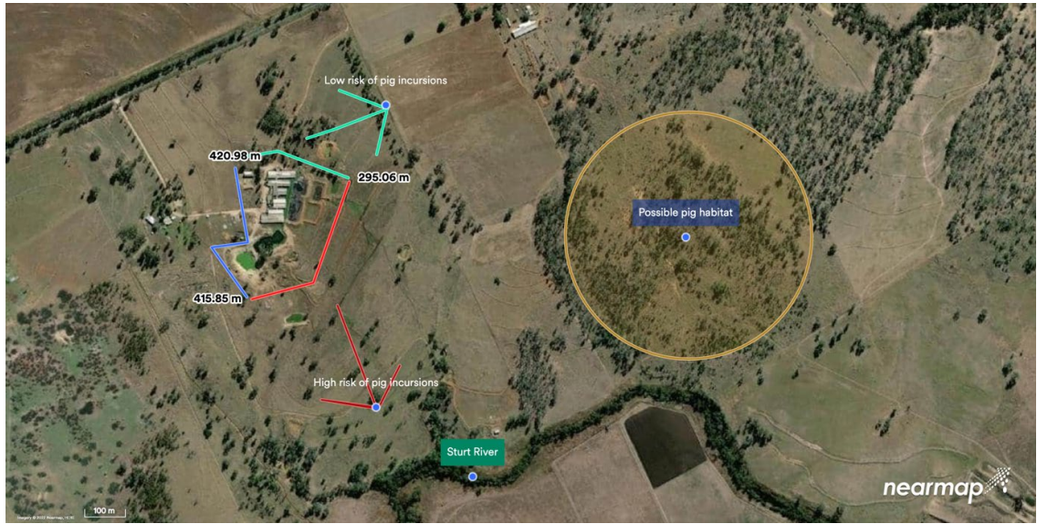
How might a model help explore ASF epidemiological, operational and policy issues?

- quantifying the importance of on-farm biosecurity
- will thinning the feral pig population during an outbreak reduce spread?
- should we prioritise the removal of feral pig carcasses?
- what are the consequences of revised estimates of feral pig density, contact rates & carcass decay rates?
- what are the consequences of changes in feral pig distribution?
- will risk-based control areas reduce welfare issues?
- is compartmentalisation feasible?
- if an ASF vaccine becomes available, will suppressive vaccination help retard an outbreak?

Further work

- New AADIS-ASF work funded by DAFF:
  - indirect spread out of abattoirs
  - risk-based control areas

- Data gaps:
  - contact rates between feral pig groups
  - contact rates between feral & domestic pigs
  - regional and seasonal influences



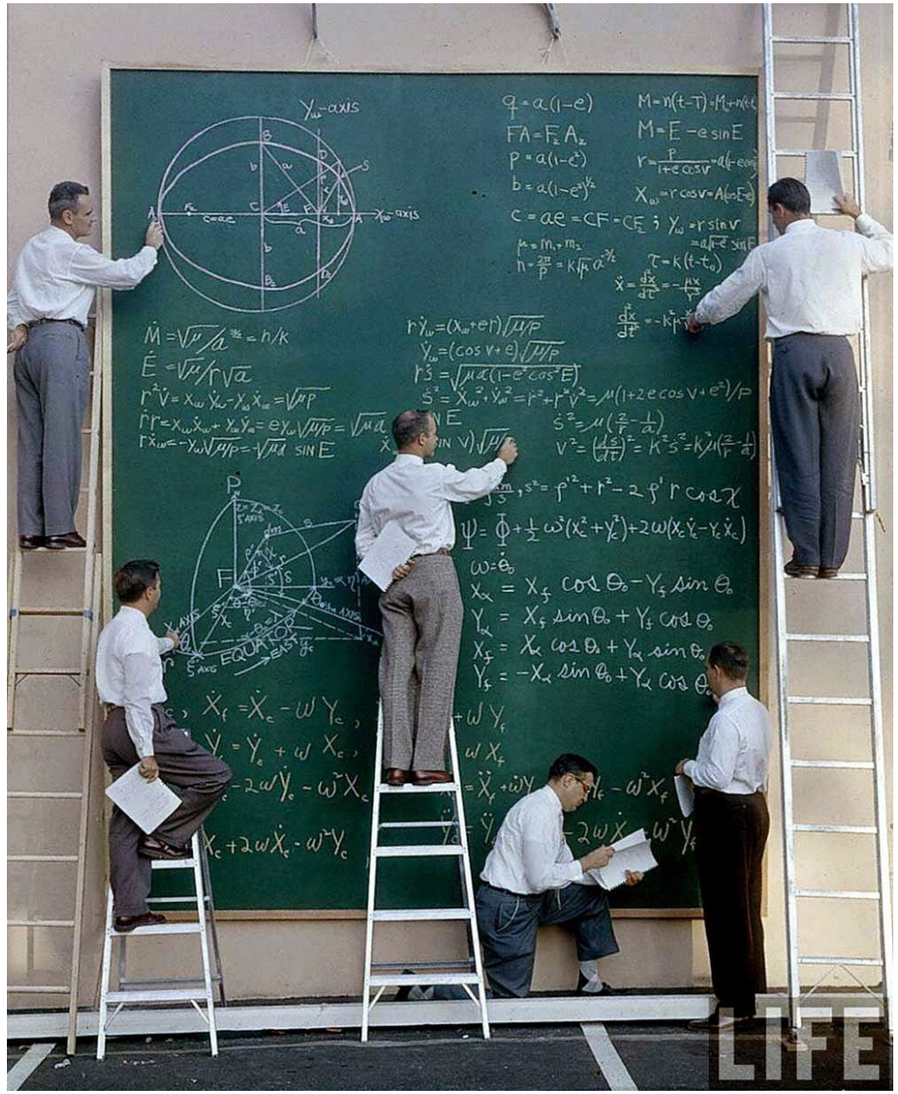
- University of Melbourne PhD candidate Maddie Oberin is investigating the domestic and feral pig interface.

- Maddie's project is a collaboration between DAWE, CEBRA, FVAS, BQ, APL, SunPork, Riverbend, the National Feral Pig Action Plan, & SQ Landscapes.

Technical highlights

AADIS
AUSTRALIAN ANIMAL DISEASE SPREAD MODEL
www.aadis.org.au

- implemented from scratch in Java (130,000 SLOCS)
- blackboard design pattern
- highly concurrent
- hybrid modelling approach (EBM, ABM, CA, Network)
- agents: herds, farms, saleyards, abattoirs, cells, people
- utilises OpenMap, Apache, and Log4J libraries
- optimised spatial queries
- single code base flavoured by configuration data
- runs locally on a Windows or Linux laptop, or in the cloud



Bradhurst R. (2015). Modelling the spatiotemporal spread and control of viral disease in livestock using a hybrid equation-based and agent-based approach. PhD Thesis, University of New England,

AADIS evolution

(function creep from an FMD model to a modelling framework)

- other highly contagious livestock diseases
- slow-burning livestock disease
- biological vector-borne disease
- mechanical vector-borne disease
- wildlife reservoirs of disease
- invasive species
- human disease
- post-graduate students
- collaborations across 20+ countries

AADIS

AUSTRALIAN ANIMAL DISEASE SPREAD MODEL

https://aadis.org.au/publications/

Collaborators

USDA United States Department of Agriculture

Australian Government
Department of Agriculture, Water and the Environment

eofmd european commission for the control of foot-and-mouth disease

UNITED NATIONS

Canadian Food Inspection Agency | Agence canadienne d'inspection des aliments
Canada

Ministry for Primary Industries
Manatū Ahu Matua

cebra
Centre of Excellence for Biosecurity Risk Analysis

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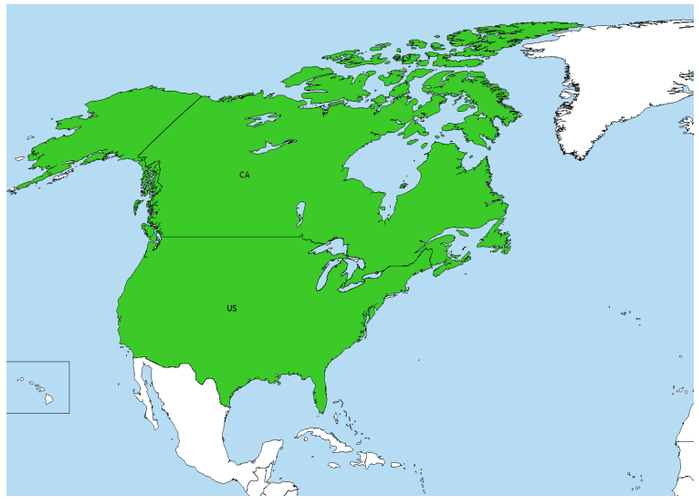

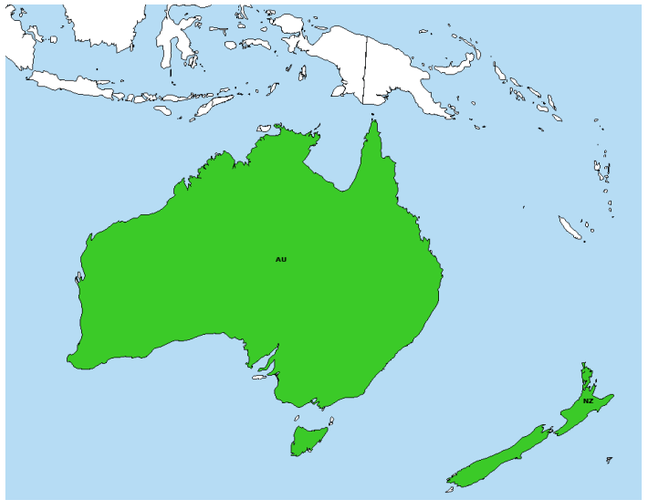

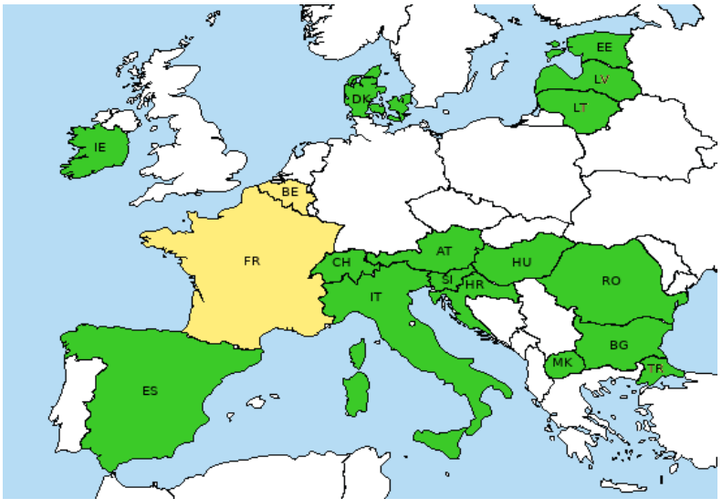

Biosecurity Queensland
Queensland Government

NATIONAL FERAL PIG ACTION PLAN

NSW Government Department of Industry

Department of Primary Industries and Regional Development
Government of Western Australia

AGRICULTURE VICTORIA

CSIRO

mla
MEAT & LIVESTOCK AUSTRALIA

AUSTRALIAN Pork

Doherty Institute

SunPork Group

murdoch children's research institute

AUSVET

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AUSVET

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Thank you

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