## Abstract

We build a simple model for an STI in Papua New Guinea, and use an existing model to determine its effect on HIV. Our model considers three main outputs: decrease in syphilis prevalence, decrease in HIV incidence, and time taken for 90% of the intervention’s effect on syphilis to happen.

## Definitions

|  |  |
| --- | --- |
| Term or abbreviation | Definition |
| FSW | Female sex workers |
| MSMW | Men who have sex with men and women |
| Incidence (of a disease per unit time) | Number of new cases of that disease in that time |
| Prevalence (of a disease) | Proportion of people who have that disease |
| PNG | Papua New Guinea |
| Sub-populations | General males, MSMW, general females and FSW |

## HIV model

For our model of HIV, we use the model from Gray et. al., 2010, with some modifications. This model uses the period from 1990 to 2010 as a calibration period, then predicts HIV levels under various intervention strategies.

Since 2010, new data has become available, causing us to revise some parameters into line with current research. In particular, as HIV clinics have spread into more areas, lower levels of HIV have been discovered. Previously, many people would have travelled to reach clinics, and would have been more likely to make the trip if they suspected they were infected. We take the view that rather than being due to a decrease in HIV, this is due to clinics in a broader part of the community having had a lower level of bias. Previously, data from heavily-affected regions was extrapolated across the country, and we take the view that this has been found to be an over-estimate. We have also found that the STI cofactor used in the model was at the top of its confidence band. We have re-fitted the model to a lower STI cofactor.

We have achieved this by varying the baseline transmission probabilities, average numbers of sex acts per partner and diagnosis and treatment rates for people with HIV.

The model accounts for STIs by allowing the user to specify a single of suppurating STIs in each sub-population, each year, and increasing the HIV transmission probability by a cofactor if either partner has an STI. It treats this as an input for the calibration stage, and it allows this level to vary during the intervention.

One major suppurating STI in PNG is syphilis. Syphilis is caused by a bacterium, Treponema pallidum pallidum, and as such is vulnerable to certain antibiotics including penicillin G benzathine and azithromycin. The other major suppurating STI, HSV-2, is caused by a virus and is not vulnerable to antibiotics. To model the effect of a PPT program for syphilis, we build a simple SIRS model for syphilis, ignoring the effects of PPT on other suppurating STIs, and ignoring any effect of HIV on syphilis transmission. By assuming independence between syphilis and other suppurating STIs, and estimating the fraction of people with suppurating STIs who have syphilis, we can also estimate the level of syphilis used in calibrating the HIV model. We can then calibrate our syphilis model to the syphilis level in the HIV model. We run our syphilis model for a variety of interventions and a variety of assumptions about the relative prevalence of syphilis among people with suppurating STIs, then calculate the corresponding STI levels. We input these into the HIV model as interventions, and thus predict the effect of our syphilis PPT on HIV transmission.

## Syphilis model

We have built a deterministic compartmental SIS-SIRS model in discrete time. We run two instances of our model per scenario, one for each region as defined by the HIV model, and we do not allow interaction between regions in our syphilis model. We split the population into four sub-populations: general males, men who have sex with men and women (MSMW), general females, and female sex workers (FSW). At any time step , a member of any population can be either susceptible or infected. If that population is undergoing PPT, that member may also be in an additional state, resistant to syphilis due to PPT. Our model contains a set of dependent parameters which allow us to calibrate our model in the no-intervention case to the levels already in use in the HIV model. Since no population is undergoing PPT in the no-intervention case, so every population contains only susceptible and infected members, we only require four dependant parameters to specify our equilibrium.

Our model uses a system of difference equations for the proportions of each sub-population that are susceptible, infected or resistant. These equations are identical between FSW, general females and general males varying only by subscripts, and are only slightly different for MSMW.

The equations for FSW are:

We provide a diagram of the possible state changes, and describe the physical meaning of each state change, in the Appendix. These equations use the following parameters:

|  |  |  |
| --- | --- | --- |
| Parameter | Description | Typical value[[1]](#footnote-1) |
|  | Proportion of FSW who are susceptible | 0.7809 |
|  | Proportion of FSW who are infected | 0.2128 |
|  | Proportion of FSW who are resistant | 0.0063 |
|  | Infection rate for FSW (see below) | 0.0109 |
|  | PPT rate for FSW (as adjusted, see below) | 0.0078 |
|  | Treatment and loss parameter | 1.2 |
|  | Time step | 1/52 |

The PPT rate is defined as follows:

|  |  |  |
| --- | --- | --- |
|  | Average number of PPT sessions per year for target group | 0.4 |
|  | Initial effectiveness of PPT | 0.98 |
|  | Increase in resistance to PPT of STI | 0.01 |
|  | Adjustment for whether FSW are targeted | 1 |
|  | Modifier based on the region | 1 |

is included to allow us to describe interventions targeting different regions differently. is included to allow us to target different sub-populations.

The force of infection, , is defined as follows:

This contains further parameters, as outlined below:

|  |  |  |
| --- | --- | --- |
|  | Proportion of general males who are infected | 0.0469 |
|  | Proportion of MSMW who are infected | 0.0536 |
|  | Weight placed on level of infection in general males | 0.96 |
|  | Infection probability (fitted by model) | -6.965 |

is the CDF of an exponential random variable with rate .

, together with the corresponding parameters for the other sub-populations, are the dependent parameters. We set these such that the equilibrium syphilis levels in the absence of PPT equals the syphilis levels we assume, , for that scenario.

We take the proportions of each sub-population which have suppurating STIs from the HIV model specifications. We then assume that a certain fraction of the people with suppurating STIs have syphilis. We allow a person to have more than one suppurating STI, and assume that having syphilis is independent of having other suppurating STIs. We calculate the assumed equilibrium syphilis and other suppurating STI levels from the overall suppurating STI level as follows:

|  |  |  |
| --- | --- | --- |
|  | Assumed proportion of FSWs infected with syphilis assuming no PPT | 0.2144 |
|  | Overall level of suppurating STIs among FSWs assuming no PPT | 0.3200 |
|  | Fraction of FSWs with suppurating STIs who have syphilis | 0.67 |
|  | Level of suppurating STIs other than syphilis among FSWs assuming no PPT | 0.1344 |

Our equations for general females, general males and MSMW are similar to those for FSW. Apart from the equation for , all equations are identical except that every subscript is replaced by a subscript or , and is replaced by in the equations for males.

|  |  |  |
| --- | --- | --- |
| Parameter | Description | Typical value[[2]](#footnote-2) |
|  | Proportion of general females who are infected | 0.0603 |
|  | Proportion of general females who are resistant | 0 |
|  | Proportion of general males who are infected | 0.0469 |
|  | Proportion of general males who are resistant | 0 |
|  | Proportion of MSMW who are infected | 0.0536 |
|  | Proportion of MSMW who are resistant | 0 |
|  | Infection rate for general females | 0.0015 |
|  | Infection rate for general males | 0.0011 |
|  | Infection rate for MSMW (see below) | 0.0013 |
|  | PPT rate for general females | 0 |
|  | PPT rate for general males | 0 |
|  | PPT rate for MSMW | 0 |
|  | Weight placed on level of infection in general females | 0.62 |
|  | Adjustment for whether general females are targeted | 0 |
|  | Adjustment for whether general males are targeted | 0 |
|  | Adjustment for whether MSMW are targeted | 0 |

The equation for the MSMW infection rate must be adjusted to allow for MSMW-MSMW transmission of syphilis. The modified equation is:

Note that, while is simply the proportion of males that are not MSMW, since we assume MSMW and general males have identical sexual behaviour with women, is much lower than the proportion of females that are not FSW, since FSW are assumed to have significantly more casual partners per person than general females. Also note that the intervention we have described reaches FSW, but not general males, general females or MSMW.

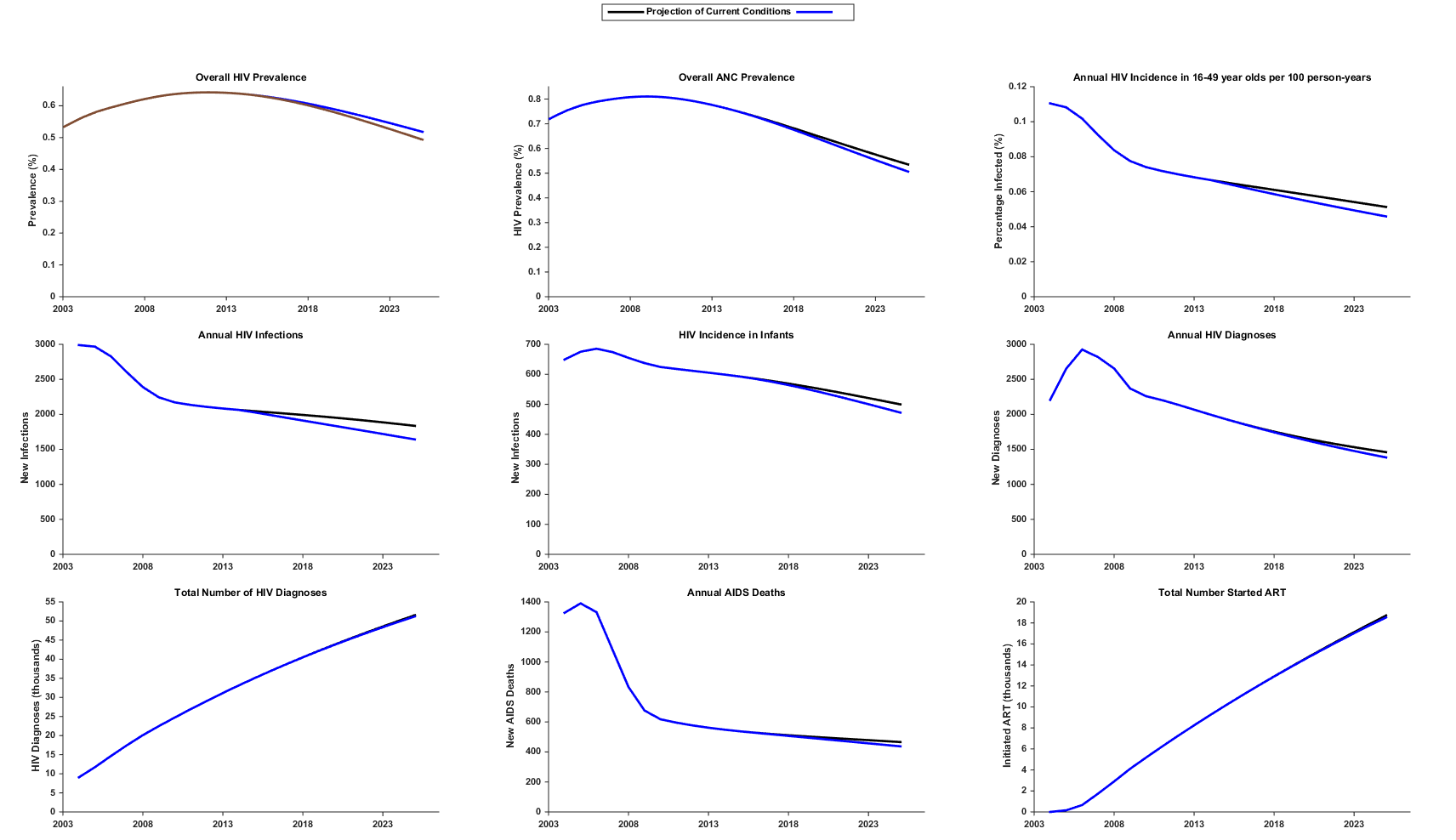
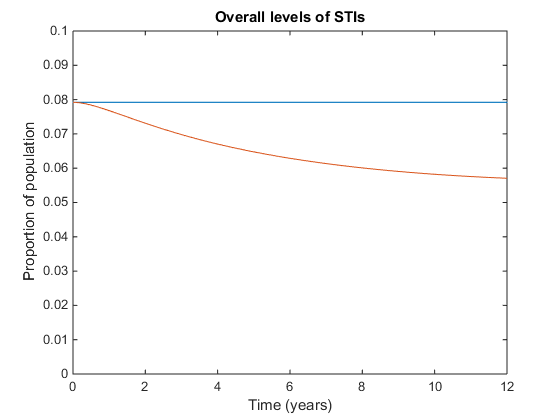
Our STI levels, and corresponding values, for these populations are as follows:

|  |  |  |
| --- | --- | --- |
|  | Assumed proportion of general females infected with syphilis assuming no PPT | 0.0603 |
|  | Assumed proportion of general males infected with syphilis assuming no PPT | 0.0469 |
|  | Assumed proportion of MSMW infected with syphilis assuming no PPT | 0.0536 |
|  | Overall level of suppurating STIs among general females assuming no PPT | 0.09 |
|  | Overall level of suppurating STIs among general males assuming no PPT | 0.08 |
|  | Overall level of suppurating STIs among MSMW assuming no PPT | 0.07 |
|  | Level of suppurating STIs other than syphilis among general females assuming no PPT | 0.0316 |
|  | Level of suppurating STIs other than syphilis among general males assuming no PPT | 0.0242 |
|  | Level of suppurating STIs other than syphilis among MSMW assuming no PPT | 0.0279 |
|  | Infection probability (fitted by model) | -1.6337 |
|  | Infection probability (fitted by model) | -0.4971 |
|  | Infection probability (fitted by model) | -0.1665 |

## Results

A full description of the results is provided in the Appendix. With a coverage of 40% for all FSW in PNG, and with no coverage for general females, males or MSMW, there is a 28.06% fall in the equilibrium prevalence of syphilis over 10 years. 50% of this impact happens within 3 years and 7 months. This causes a fall of 10.56% in nationwide HIV levels. Providing PPT to general males and females at the same level as to FSW provides a large impact, but this is because there are far more general males and females than FSW. Providing the same number of total treatment doses but distributing these across the whole population results in almost no benefit (0.95% reduction in suppurating STIs, 0.47% reduction in HIV). Providing PPT to MSMW at the same level as to FSW provides little additional benefit (2% further decrease in suppurating STIs).

|  |  |  |  |
| --- | --- | --- | --- |
| Scenario | Percentage drop in syphilis prevalence after 10 years | Percentage drop in HIV incidence after 10 years | Time it takes for syphilis to fall 50% towards this level |
| Default intervention | 0.7194 | 0.8944 | 3.6069 |

****

## Appendix

Diagram showing the possible state changes in the model

Diagram 1: The possible states, and possible movements between states over a single period, in our model.

Susceptible

Move off treatment, and remain susceptible

Treatment and loss rate

Infection rate

PPT rate for susceptibles

Infected

Move off treatment and be infected immediately

PPT rate for infected

Resistant

|  |  |  |
| --- | --- | --- |
| Probability of state change (m1) | Description | Footnote |
|  | Infection rate | m2 |
|  | Existing treatment and loss rate | m3 |
|  | PPT rate for susceptible | m4 |
|  | PPT rate for infected | m5 |
|  | Move off PPT, then remain susceptible for one period | m6 |
|  | Move off PPT, then become infected in the same period[[3]](#footnote-3) | m7 |

Results of all scenarios

|  |  |  |  |
| --- | --- | --- | --- |
| Scenario | Percentage drop in syphilis prevalence after 10 years | Percentage drop in HIV incidence after 10 years | Time it takes for syphilis to fall 50% towards this level |
| Default intervention | 0.7194 | 0.8944 | 3.6069 |
| Increase to 0.70 | 0.744 | 0.9029 | 3.7196 |
| Decrease to 0.56 | 0.7049 | 0.8894 | 3.5492 |
| Increase to 0.99 | 0.7187 | 0.8942 | 3.6069 |
| Decrease to 0.92 | 0.7202 | 0.8947 | 3.6069 |
| Increase and to 0.50 | 0.4894 | 0.8131 | 2.4862 |
| Increase and to 1.00 | 0.398 | 0.7749 | 1.8104 |
| Increase to 0.50 | 0.7081 | 0.8886 | 3.5658 |
| Increase to 1 | 0.6994 | 0.8841 | 3.5438 |
| Decrease to 0.00 | 0.7627 | 0.9251 | 3.0954 |
| Decrease to 0.50 | 0.7384 | 0.9075 | 3.615 |
| Decrease to 0.00 | 0.9566 | 0.9689 | 0.5308 |
| Decrease to 0.50 | 0.8262 | 0.927 | 3.6235 |
| Decrease to 0.20 | 0.8453 | 0.9402 | 3.6315 |
| Increase to 0.60 | 0.6224 | 0.8602 | 3.5412 |
| Decrease to 0.90 | 0.7312 | 0.8986 | 3.6262 |
| Increase to 0.98 | 0.7124 | 0.8919 | 3.6069 |
| Decrease to | 0.6834 | 0.8856 | 4.0081 |
| Increase to | 0.7589 | 0.904 | 3.1481 |
| Decrease to 0.50 | 0.7611 | 0.9135 | 3.9258 |
| Increase to 0.83 | 0.6978 | 0.8811 | 3.2854 |
| Distribute the same number of treatments as in the default scenario across the whole population | 0.9905 | 0.9953 | 2.8538 |
| Distribute the same number of treatments as in the default scenario across FSW and MSMW | 0.916 | 0.9613 | 3.5546 |

|  |  |  |  |
| --- | --- | --- | --- |
| Scenario | Percentage drop in syphilis after 10 years | Time it takes for syphilis to fall to 90% towards this level | Percentage drop in HIV after 10 years |
|  |  |  |  |
|  |  |  |  |

1. We supply values for a rural population one time step into a typical intervention [↑](#footnote-ref-1)
2. We supply values for a rural population one time step into a typical intervention [↑](#footnote-ref-2)
3. m1: These formulas use the following parameters:

   m2: We include the term because some people who were susceptible at time immediately receive PPT and enter the resistant group, then later perform sexual acts which would otherwise have infected them. Because these people are now resistant, they do not become infected.

   m3: This accounts for all treatment other than PPT, as well as losses and births. Congenital syphilis has a very high mortality rate, and very few people infected at birth survive to enter the sexual population.

   m4-m5: Because this only accounts for PPT, which is by definition presumptive, we assume that it is the same for susceptible and infected people. If a person suspects that they might be infected and seeks testing or treatment because of this, we assume that they would have done so anyway, and thus we include it in arrow 2.

   m6-m7: We set the time step of our model equal to the duration of protection, so that the entire resistant population from one period becomes susceptible again at the start of the next period. These people have the same probabilities of remaining susceptible or being infected as the already susceptible people, except that we assume they will not receive PPT immediately after they lose their protection, for at least one period. [↑](#footnote-ref-3)