The Papua New Guinea HIV Model - Technical Appendix

Technical Details and Calibration of the PNG HIV Model

The Kirby Institute for Infection and Immunity in Society

Australian Government
AusAID

Introduction

This technical appendix provides a detailed description of the PNG HIV Model summarised in "The Papua New Guinea HIV Model – Summary and Results" report. A full overview of the modelling methodology used to development the model is presented with all the assumptions used described in detail. This is followed by a description and justification of all the calibrated parameter values used to represent the overall HIV epidemic in PNG. Detailed descriptions of the methods and parameters underlying the PNG HIV Model are provided in this appendix in a transparent manner such that the strengths and limitations of the model can be clearly assessed and the PNG HIV Model can be reproduced and improved by any other mathematical modelling group. The software interface running the model can be used without understanding the methods underlying the model. However, this software is not meant to be used as a 'black box' and awareness of the processes and calculation involved in producing all results can be obtained by understanding the equations and methods provided in this technical appendix.

Table of Contents

Description of the PNG HIV Model

The PNG HIV Model has been designed to specifically represent the unique behavioural and epidemiological context of Papua New Guinea. It is based on best-practise epidemic disease modelling and describes the population demographics and characteristics of distinct population groups, the mixing and sexual partnerships between population groups, HIV disease progression and treatment, and the transmission of HIV infection.

Population structure and groups

HIV epidemiological data from PNG and recent estimates of HIV prevalence show a widely varying HIV epidemic depending on geographical location [1-3]. In particular there appears to be large differences between urban and rural areas within PNG. To capture these differences the overall population simulated in the model is split into two population categories which can represent the overall urban population and the overall rural population within PNG (as in the main report) but are arbitrary and could represent other population divisions. For example, one population category could represent the population living in Port Moresby while the other category represents the rest of the PNG population. From now on in this report these population categories will be referred to as the urban and rural population, respectively.

The population within each population category is divided into specific groups containing individuals with different behavioural characteristics. Through consultation with stakeholders in PNG it was determined that there are at least 4 distinct behavioural population groups that are important in PNG for the transmission of HIV. These are:

- General heterosexual males
- Men who have sex with men and women (MSMW)
- General females
- Female sex workers (FSW)

A population group representing men who have sex with men (MSM) has not been included in the model because the majority of men who report having had sex within another man also engage in sexual intercourse with women [4-7] and there are very few recorded HIV diagnoses attributed to homosexual intercourse [1]. Any men who are exclusively homosexual are included in this group. A schematic of the population groups incorporated in the PNG HIV model is shown in Figure 1. The population in each group is binned into 5 year age groups with people over 60 years of age group together: 0-4 years, 5-9, 10-14, 15-19, 20-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, > 60 years.

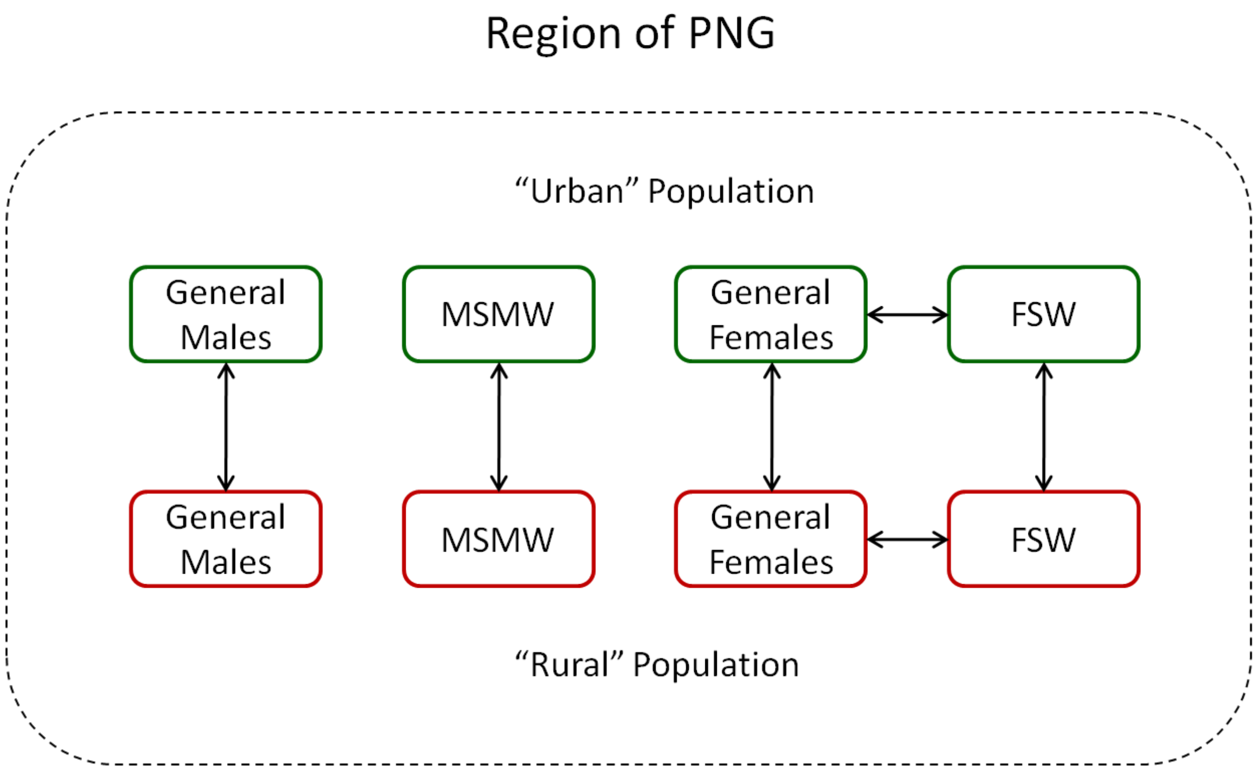


Figure 1: Schematic showing the division of the PNG population into the distinct population groups represented in the PNG HIV Model. Within PNG overall or a specific region of PNG the populations divided into two categories the "urban" and "rural" population (this division can be arbitrary) which are then further divided into 4 population groups.

Individuals can move between urban and rural areas through migration but when they migrate they remain in the same age group, HIV infection stage, and population group as shown by the arrows in Figure 1. In addition within urban rural areas general females can start sex work and become a FSW and FSWs can stop sex work and return to being a general female.

Disease Progression

For each population and age group shown in Figure 1, individuals are categorized into one of 11 health states. These health states are: uninfected; undiagnosed primary HIV infection; diagnosed primary HIV infection; undiagnosed chronic HIV infection; diagnosed chronic HIV infection; undiagnosed AIDS; diagnosed AIDS; first line ART; first line ART failure; 2nd line ART; and 2nd line ART failure. The movement of people between these stages due to infection, disease progression, and initiation of treatment are shown in Figure 2.

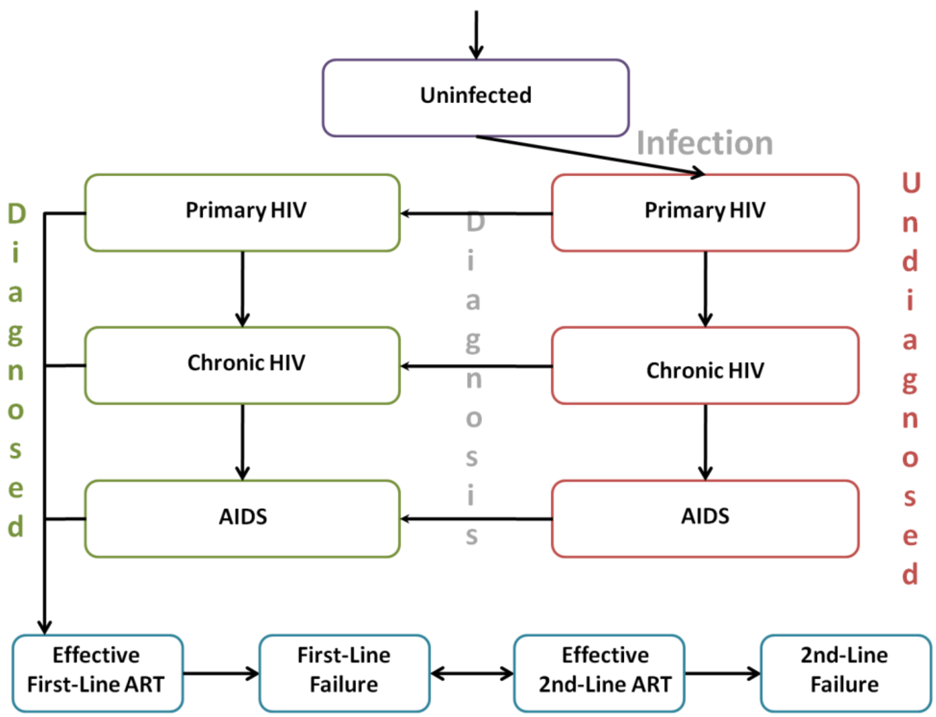


Figure 2: Health states used incorporated in the model representing HIV disease stages.

The movement of people between population/age groups and the disease stages in Figure 2 is described by a system of difference equations using a 1 month time step (which is representative of the smallest time gap between recorded data values). The mathematical form of the equations for the number of people within each health state, with respect to time, is shown below. For each symbol, representing a transition rate between population groups or diseases stages, a real-world meaning is provided above each term with a more detailed description for some symbols provided below the equations. This set of 11 equations is in matrix form encapsulating each age group within a particular population category. The difference equations listed below describe the change in the number of people in each health state every time period. The PNG HIV Model incorporates these 11 matrix equations (health states) specific for each of the 8 population groups and 13 age groups, effectively leading to 1144 difference equations. The number of people in each compartment changes based on per-capita rates of aging, migration, disease progression, HIV testing, initiation of treatment, and mortality. This system of equations is used to reflect the dynamics of HIV epidemics in PNG and allows for differential levels of infectiousness by population group and stage of infection.

$$\overbrace{S_t}^{\substack{\text{Number}\\ \text{uninfected}\\ \text{current time}}} = \overbrace{S_{t-1}}^{\substack{\text{Number uninfected}\\ \text{previous time-step}}} + \overbrace{M'S'_{t-1}}^{\substack{\text{Number that}\\ \text{migrate in}}} + \overbrace{\pi}^{\substack{\text{New}\\ \text{entry into}\\ \text{population}}} + \overbrace{\Sigma^* S^*_{t-1}}^{\substack{\text{Number that enter}\\ \text{population class}}} + \left(\overbrace{A}^{\substack{\text{Aging}\\ \text{rate}}} - \overbrace{C}^{\substack{\text{Circumcision}\\ \text{rate}}} - \overbrace{M}^{\substack{\text{Migration}\\ \text{rate out}}} - \overbrace{\Sigma}^{\substack{\text{Rate of leaving}\\ \text{population class}}} - \overbrace{\mu}^{\substack{\text{Background}\\ \text{death rate}}} - \overbrace{\lambda}^{\substack{\text{Per-capita rate}\\ \text{of acquiring HIV}}} \right) S_{t-1}$$

$$\overbrace{U_t^p}^{\substack{\text{Number with}\\ \text{undiagnosed}\\ \text{primary infection}}} = \overbrace{U_{t-1}^p}^{\substack{\text{Number previous}\\ \text{time-step}}} + \overbrace{\lambda S_{t-1}}^{\substack{\text{New}\\ \text{Infections}}} + \overbrace{M'U_{t-1}^{p'}}^{\substack{\text{Number that}\\ \text{migrate in}}} + \overbrace{\Sigma^* U_{t-1}^{p*}}^{\substack{\text{Number that enter}\\ \text{population class}}} + \left(\overbrace{A}^{\substack{\text{Aging}\\ \text{rate}}} - \overbrace{M}^{\substack{\text{Migration}\\ \text{rate out}}} - \overbrace{\Sigma}^{\substack{\text{Rate of leaving}\\ \text{population class}}} - \overbrace{\mu}^{\substack{\text{Background}\\ \text{death rate}}} - \overbrace{\mu_p}^{\substack{\text{HIV-related}\\ \text{death (primary)}}} - \overbrace{\gamma_p}^{\substack{\text{Progression}\\ \text{to chronic HIV}}} + \overbrace{\eta}^{\substack{\text{Testing or}\\ \text{diagnosis rate}}} \right) U_{t-1}^p$$

$$\overbrace{U_t^c}^{\substack{\text{Number with}\\ \text{undiagnosed}\\ \text{chronic infection}}} = \overbrace{U_{t-1}^c}^{\substack{\text{Number previous}\\ \text{time-step}}} + \overbrace{\gamma_p U_{t-1}^p}^{\substack{\text{Progression}\\ \text{to chronic HIV}}} + \overbrace{M'U_{t-1}^{c'}}^{\substack{\text{Number that}\\ \text{migrate in}}} + \overbrace{\Sigma^* U_{t-1}^{c*}}^{\substack{\text{Number that enter}\\ \text{population class}}} + \left(\overbrace{A}^{\substack{\text{Aging}\\ \text{rate}}} - \overbrace{M}^{\substack{\text{Migration}\\ \text{rate out}}} - \overbrace{\Sigma}^{\substack{\text{Rate of leaving}\\ \text{population class}}} - \overbrace{\mu}^{\substack{\text{Background}\\ \text{death rate}}} - \overbrace{\mu_c}^{\substack{\text{HIV-related}\\ \text{death (chronic)}}} - \overbrace{\gamma_c}^{\substack{\text{Progression}\\ \text{to AIDS}}} - \overbrace{\eta}^{\substack{\text{Testing or}\\ \text{diagnosis rate}}} \right) U_{t-1}^c$$

$$\overbrace{U_t^a}^{\substack{\text{Number with}\\ \text{undiagnosed}\\ \text{AIDS}}} = \overbrace{U_{t-1}^a}^{\substack{\text{Number previous}\\ \text{time-step}}} + \overbrace{\gamma_c U_{t-1}^c}^{\substack{\text{Progression}\\ \text{to AIDS}}} + \overbrace{M'U_{t-1}^{a'}}^{\substack{\text{Number that}\\ \text{migrate in}}} + \overbrace{\Sigma^* U_{t-1}^{a*}}^{\substack{\text{Number that enter}\\ \text{population class}}} + \left(\overbrace{A}^{\substack{\text{Aging}\\ \text{rate}}} - \overbrace{M}^{\substack{\text{Migration}\\ \text{rate out}}} - \overbrace{\Sigma}^{\substack{\text{Rate of leaving}\\ \text{population class}}} - \overbrace{\mu}^{\substack{\text{Background}\\ \text{death rate}}} - \overbrace{\mu_c}^{\substack{\text{HIV-related}\\ \text{death (chronic)}}} - \overbrace{\eta_a}^{\substack{\text{AIDS}\\ \text{diagnosis rate}}} \right) U_{t-1}^a$$

$$\overbrace{D_t^p}^{\substack{\text{Number with}\\ \text{diagnosed}\\ \text{primary infection}}} = \overbrace{D_{t-1}^p}^{\substack{\text{Number previous}\\ \text{time-step}}} + \overbrace{\eta U_{t-1}^p}^{\substack{\text{New}\\ \text{Diagnoses}}} + \overbrace{M' D_{t-1}^{p'}}^{\substack{\text{Number that}\\ \text{migrate in}}} + \overbrace{\Sigma^* D_{t-1}^{p*}}^{\substack{\text{Number that enter}\\ \text{population class}}} + \left(\overbrace{A}^{\substack{\text{Aging}\\ \text{rate}}} - \overbrace{M}^{\substack{\text{Migration}\\ \text{rate out}}} - \overbrace{\Sigma}^{\substack{\text{Rate of leaving}\\ \text{population class}}} - \overbrace{\mu}^{\substack{\text{Background}\\ \text{death rate}}} - \overbrace{\mu_p}^{\substack{\text{HIV-related}\\ \text{death (primary)}}} - \overbrace{\gamma_p}^{\substack{\text{Progression}\\ \text{to chronic HIV}}} - \overbrace{\tau_p}^{\substack{\text{Treatment}\\ \text{rate (primary)}}} \right) D_{t-1}^p$$

$$\overbrace{D_t^c}^{\substack{\text{Number with}\\ \text{diagnosed}\\ \text{chronic infection}}} = \overbrace{D_{t-1}^c}^{\substack{\text{Number previous}\\ \text{time-step}}} + \overbrace{\eta U_{t-1}^c}^{\substack{\text{New}\\ \text{Diagnoses}}} + \overbrace{M' D_{t-1}^{c'}}^{\substack{\text{Number that}\\ \text{migrate in}}} + \overbrace{\Sigma^* D_{t-1}^{c*}}^{\substack{\text{Number that enter}\\ \text{population class}}} + \overbrace{\gamma_p D_{t-1}^p}^{\substack{\text{Progression to}\\ \text{chronic HIV}}} + \left(\overbrace{A}^{\substack{\text{Aging}\\ \text{rate}}} - \overbrace{M}^{\substack{\text{Migration}\\ \text{rate out}}} - \overbrace{\Sigma}^{\substack{\text{Rate of leaving}\\ \text{population class}}} - \overbrace{\mu}^{\substack{\text{Background}\\ \text{death rate}}} - \overbrace{\mu_c}^{\substack{\text{HIV-related}\\ \text{death (primary)}}} - \overbrace{\gamma_c}^{\substack{\text{Progression}\\ \text{to AIDS}}} - \overbrace{\tau_c}^{\substack{\text{Treatment}\\ \text{rate (chronic)}}} \right) D_{t-1}^c$$

$$\overbrace{D_t^a}^{\substack{\text{Number with}\\ \text{diagnosed}\\ \text{AIDS}}} = \overbrace{D_{t-1}^a}^{\substack{\text{Number previous}\\ \text{time-step}}} + \overbrace{\eta U_{t-1}^a}^{\substack{\text{New AIDS}\\ \text{Diagnoses}}} + \overbrace{M' D_{t-1}^{a'}}^{\substack{\text{Number that}\\ \text{migrate in}}} + \overbrace{\Sigma^* D_{t-1}^{a*}}^{\substack{\text{Number that enter}\\ \text{population class}}} + \overbrace{\gamma_c D_{t-1}^c}^{\substack{\text{Progression to}\\ \text{AIDS}}} + \left(\overbrace{A}^{\substack{\text{Aging}\\ \text{rate}}} - \overbrace{M}^{\substack{\text{Migration}\\ \text{rate out}}} - \overbrace{\Sigma}^{\substack{\text{Rate of leaving}\\ \text{population class}}} - \overbrace{\mu}^{\substack{\text{Background}\\ \text{death rate}}} - \overbrace{\mu_a}^{\substack{\text{HIV-related}\\ \text{death (primary)}}} - \overbrace{\tau_a}^{\substack{\text{Treatment}\\ \text{rate (AIDS)}}} \right) D_{t-1}^a$$

$$\overbrace{T_t^1}^{\substack{\text{Number on}\\ \text{effective 1st}\\ \text{line ART}}} = \overbrace{T_{t-1}^1}^{\substack{\text{Number previous}\\ \text{time-step}}} + \overbrace{\tau_p D_{t-1}^p + \tau_c D_{t-1}^c + \tau_a D_{t-1}^a}^{\substack{\text{Number that initiate ART}\\ \text{from each HIV disease stage}}} + \overbrace{M' T_{t-1}^{1'}}^{\substack{\text{Number that}\\ \text{migrate in}}} + \overbrace{\Sigma^* T_{t-1}^{1*}}^{\substack{\text{Number that enter}\\ \text{population class}}} + \left(\overbrace{A}^{\substack{\text{Aging}\\ \text{rate}}} - \overbrace{M}^{\substack{\text{Migration}\\ \text{rate out}}} - \overbrace{\Sigma}^{\substack{\text{Rate of leaving}\\ \text{population class}}} - \overbrace{\mu}^{\substack{\text{Background}\\ \text{death rate}}} - \overbrace{\mu_t}^{\substack{\text{HIV-related}\\ \text{death (effective ART)}}} - \overbrace{\omega_1}^{\substack{\text{1st-line ART}\\ \text{failure rate}}} \right) T_{t-1}^1$$

$$\overbrace{F_t^1}^{\substack{\text{Number}\\ \text{failed 1st}\\ \text{line ART}}} = \overbrace{F_{t-1}^1}^{\substack{\text{Number previous}\\ \text{time-step}}} + \overbrace{\omega_1 T_{t-1}^1}^{\substack{\text{Number failed}\\ \text{1st-line ART}}} + \overbrace{M' F_{t-1}^{1'}}^{\substack{\text{Number that}\\ \text{migrate in}}} + \overbrace{\Sigma^* F_{t-1}^{1*}}^{\substack{\text{Number that enter}\\ \text{population class}}} + \left(\overbrace{A}^{\substack{\text{Aging}\\ \text{rate}}} - \overbrace{M}^{\substack{\text{Migration}\\ \text{rate out}}} - \overbrace{\Sigma}^{\substack{\text{Rate of leaving}\\ \text{population class}}} - \overbrace{\mu}^{\substack{\text{Background}\\ \text{death rate}}} - \overbrace{\mu_f}^{\substack{\text{HIV-related}\\ \text{death (ART failure)}}} - \overbrace{\tau_2}^{\substack{\text{2nd-line ART}\\ \text{treatment rate}}} \right) F_{t-1}^1$$

$$\overbrace{T_t^2}^{\substack{Number\ on\\ effective\ 2nd\\ line\ ART}} = \overbrace{T_{t-1}^2}^{\substack{Number\ previous\\ time-step}} + \overbrace{\tau_2 F_{t-1}^1}^{\substack{Number\ starting\\ 2nd-line\ ART}} + \overbrace{M' T_{t-1}^{2'}}^{\substack{Number\ that\\ migrate\ in}} + \overbrace{\Sigma^* T_{t-1}^{2*}}^{\substack{Number\ that\ enter\\ population\ class}}$$
$$+ \left(\overbrace{A}^{\substack{Aging\\ rate}} - \overbrace{M}^{\substack{Migration\\ rate\ out}} - \overbrace{\Sigma}^{\substack{\text{Rate of leaving}\\ \text{population class}}} - \overbrace{\mu}^{\substack{Background\\ death\ rate}} - \overbrace{\mu_t}^{\substack{HIV-related\\ death\ (effective\ ART)}} - \overbrace{\omega_2}^{\substack{2nd-line\ ART\\ failure\ rate}} \right) T_{t-1}^2$$

$$\overbrace{F_t^2}^{\substack{Number\\ failed\ 2nd\\ line\ ART}} = \overbrace{F_{t-1}^2}^{\substack{Number\ previous\\ time-step}} + \overbrace{\omega_2 T_{t-1}^2}^{\substack{Number\ failed\\ 2nd-line\ ART}} + \overbrace{M' F_{t-1}^{2'}}^{\substack{Number\ that\\ migrate\ in}} + \overbrace{\Sigma^* F_{t-1}^{2*}}^{\substack{Number\ that\ enter\\ population\ class}}$$
$$+ \left(\overbrace{A}^{\substack{Aging\\ rate}} - \overbrace{M}^{\substack{Migration\\ rate\ out}} - \overbrace{\Sigma}^{\substack{\text{Rate of leaving}\\ \text{population class}}} - \overbrace{\mu}^{\substack{Background\\ death\ rate}} - \overbrace{\mu_f}^{\substack{HIV-related\\ death\ (ART\ failure)}} \right) F_{t-1}^2$$

All of the symbols in the equations represent matrices containing age-specific per-capita rates of population movement between HIV health states or population groups. In particular:

- A is a matrix describing the rate that individuals move from one age group to another

$$A = \begin{pmatrix} -\alpha & 0 & 0 & \cdots & 0 \\ \alpha & -\alpha & 0 & \cdots & 0 \\ 0 & \alpha & -\alpha & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & 0 \\ 0 & \cdots & 0 & \alpha & 0 \end{pmatrix}$$

  where α is the rate that individuals age from one 5 year age group to another.
- M and M' are diagonal matrices that describe the rate that individuals in each age group migrate from one population class to another (used to represent urban-rural migration). These rates can be different for different population and age groups and the rate from urban to rural areas can be different to rural to urban rates. The $'$ is used represent the corresponding population group in the other population class (urban or rural).
- Σ and Σ^* are diagonal matrices that are only non zero for female populations and describe the rate that general females in each age group become FSWs and vice versa. The * in this case is used to represents all other population groups that may become the population group the equations are referring to.
- C is a diagonal matrix describing the rate that males in each age group are circumcised (for females this is a zero matrix). This matrix can be different for general males and MSMW with rates that vary across age groups.

For males penile cutting and circumcision is only tracked for susceptible males. Once infected all males move into the primary infection stage and their circumcision status is no longer followed.

Transmission of HIV Infection

The per-capita rate of becoming infected or 'force of infection' is the most important factor in describing infectious disease dynamics. The force of infection depends on the sexual behaviour in populations and the sexual mixing between population groups. In particular the annual per-capita risk of acquiring HIV infection per uninfected person through sexual transmission depends on:

- the number of people or prevalence of HIV in each HIV-infected stage
- the average number of casual and regular sexual partnerships per person per year
- the average frequency of sexual acts per partnership
- the proportion of acts in which condoms are used
- the efficacy of condoms
- the proportion and efficacy of penile cutting or circumcision (for female to male transmission), and
- the prevalence of ulcerating STIs within each population group
- whether an effective microbicide has been used by females
- whether males are circumcised or have penile cutting
- the efficacy of circumcision and penile cutting in preventing HIV acquisition

The force of infection is calculated every time step in the PNG HIV Model to take into account temporal variations in parameter values and epidemic dynamics. It is expressed mathematically using standard modelling methods which combine the specific risk factors listed above into a binomial expression for the accumulation of risk over multiple exposures. This expression is then used to quantify the average per-capita risk of acquiring infection for individuals in each population and age group.

Separate force of infection expressions are used for casual, regular, and commercial partnerships and for each combination of pairings between individuals of different population, age, and health state groups. For each of the possible partnership pairings the equation for the force of infection for all male and female populations has the following forms

$$\lambda_j{}^F(t) = c\left[1-(1-(1-\epsilon_m)\beta)^{np_m(1-p_c)}(1-(1-\epsilon_c)\beta)^{np_c}(1-\beta)^{(1-p_c)(1-p_m)}\right]P_{HIV},$$

and

$$\lambda_j{}^M(t) = c[1-(1-(1-\epsilon_c)(1-\epsilon_{circ})\beta)^{np_c}(1-(1-\epsilon_{circ})\beta)^{np_c(1-p_c)}]P_{HIV},$$

respectively, where c is the average number of sexual partners, n is the frequency of sex in the given partnership, p_c is the frequency of condom use, p_m is the frequency of unprotected sex acts where a female uses a microbicide, ϵ_c is the efficacy of condoms, ϵ_m is the efficacy of microbicides in preventing females becoming infected, ϵ_{circ} is the efficacy of penile cutting/circumcision in protecting males from acquiring HIV from females ($\epsilon_{circ} = 0$ in the following two cases: if the susceptible population group consists of uncircumcised males; or if the corresponding partnership is homosexual), P_{HIV} is the dynamic HIV prevalence in the pool of potential partners for a given sexual mixing interaction (including population group, age group, and health state), and β is the probability of transmission per unprotected sexual act for the given partnership type. The value of β depends on the presence of STIs within partners, the HIV health state of partners, and whether the potential HIV transmission is male-to-female, female-to-male, or male-to-male. It is given by the following mathematical form

$$\beta = W[(1-p_{STI})\beta_{ref} + p_{STI}f_{STI}\beta_{ref}],$$

where p_{STI} is the probability that at least one sexual partner has an STI, f_{STI} is the relative increase in transmission probability due to the presence of an STI, W is the relative change in transmission probability due to the health state of the infected partner (increase for partners with primary HIV infection or AIDS and lower for partners on effective ART), and β_{ref} is the reference transmission probability from someone in the chronic stage of HIV infection and where there are no STIs in either partner. The reference transmission probability, β_{ref}, can take one of three values representing male-to-female, female-to-male, or male-to-male transmission. To calculate the overall risk of a HIV negative person in a specific population and age group acquiring infection, the risk is summed over each partnership type and health state ($\lambda = \Sigma_j \lambda_j$).

The PNG HIV Model also incorporates mother-to-child transmission and estimates probabilistically the number of infants infected each year. In the model the annual number of infected infants for each female age group takes the following form

$$N = B[\{(1-p_{mtc})+(1-\epsilon_{mtc})p_{mtc}\}\beta_{mtc}F_U + (1-\epsilon_{ART})\beta_{mtc}F_T],$$

where B is the birth-rate of the selected female age group, p_{mtc} is the probability that an infected female not already on ART undertakes prevention of mother-to-child therapies/procedures (PMTCT), ϵ_{mtc} is the overall efficacy of PMTCT in preventing infant infection, β_{mtc} is the underlying risk of an infant acquiring HIV from their HIV infected mother if the mother is not on treatment or is not taking PMTCT, F_U is the number of females infected with HIV that are not taking ART, ϵ_{ART} is the overall efficacy of ART (for women taking ART) in preventing infant infection, and F_T is the number of HIV infected women taking ART for their own infection. The total number of infants infected each year is then obtained by summing over female population and age groups.

Sexual partnerships between population groups

HIV transmission in the PNG HIV Model occurs through sex within a HIV discordant partnership. Partnerships can occur as regular or casual partnerships between the population groups shown in

Table 1. Note that individuals can only have partnerships with people in the same population category (urban/rural area).

Table 1: Possible sexual partnerships between population groups in PNG HIV Model. Population groups listed as rows can have casual or regular partnerships with population listed across the top of the table if the corresponding intersecting rectangle is labelled with a P.

		Urban Areas				Rural Areas			
		General Males	**MSMW**	**General Females**	**FSW**	**General Males**	**MSMW**	**General Females**	**FSW**
Urban Areas	**General Males**			P	P				
	MSMW		P	P	P				
	General Females	P	P						
	FSW	P	P						
Rural Areas	**General Males**							P	P
	MSMW						P	P	P
	General Females					P	P		
	FSW					P	P		

To calculate the per-capita force of infection, the number of each type of partnership males and females in each age have with individuals in other population age groups needs to be calculated. For each female population group the total number of partners each age group has with males is entered as a user input. From this entered value the PNG HIV Model determines the number of partnerships with each male age group. Due to a lack of data on age assortativity of partnerships, the model uses a Poisson distribution to distribute the number of partners within an age group across male age groups with a mean value that can vary across the female age groups and represents the average age difference between male and female partners. This type of distribution has been used for low income settings in Africa and is a reasonable representation of the likely distribution in PNG [8]. After the Poisson distribution is generated for each age the distribution is then binned into 5 year age groups. For MSMW-MSMW partnerships there is no age assortativity and the number of partnerships a particular age group has per year are uniformly distributed across the sexually active MSMW age groups.

To ensure there is a conversation of sexual partnerships between males and females, the per-capita number of partnerships each male population group has with females each year is balanced with the number of partnerships females have with males; for example, the total number of partnerships FSWs have with males is equal to the total number of partnerships males have with FSWs. This means that if a female population group consisting of $\mathrm{N_a}$ females has $\mathrm{c_{ab}}$ sexual partnerships each year with males in a population of $\mathrm{N_b}$ males then $\mathrm{c_{ab}N_a} = \mathrm{c_{ba}N_b}$ where a represents the female population group, b represents the male population group, and $\mathrm{c_{ba}}$ is the number of sexual partnerships males have with the female population group.

Model Simulation and Calibration Process

The PNG HIV model simulates HIV transmission in PNG through four stages:

1. **Population set-up:** In this stage the demographic parameters are set to their initial values and used to generate an initial population. The model is run without HIV transmission for 50 years to establish the correct population proportions and distribution in each population and age group. The final population distribution is saved and used in the next simulation stage.

2. **HIV infection set-up:** Approximately 10 undiagnosed HIV infected people in the primary stage of infection are entered into the model population with the initial population size reset to the 1990 value and using the population distribution obtained from the population burn in stage. The model is then run for 13 years with the sexual behaviour, HIV biology and transmission parameters, and HIV clinical parameters fixed at the their initial values for 1990 to establish the appropriate distribution of HIV infections across the population categories and age groups. It is assumed over this time period that infected people are only diagnosed clinically in the AIDS stage. The resulting population distribution is then used in the next simulation stage.

3. **Simulation of HIV epidemic from 1990 to 2010:** The population proportions returned from the HIV burn in stage with the initial overall population size are used to initialize the model at the start of 1990. The model is then run to simulate the past HIV epidemic in PNG from the start of 1990 to the end of 2010 (or another specified end year). Over this time period the parameter values used are no longer constant over time (as for the previous two simulation stages) and can be varied from year to year to match the changing conditions over this time. The model results for this period are saved and allow the impact of evaluation scenarios to be investigated. The final population sizes for each population and age group at the end of this time period are used to represent current conditions for the simulations of future interventions.

After establishing a baseline HIV epidemic for the 1990 to 2010 period, “what if?” past evaluation scenarios can be investigated by changing parameters from their default values and comparing the resulting simulated epidemic to the reference epidemic for the 1990 to 2010 period.

4. **Simulation of interventions:** To forecast the impact of interventions the overall population size and distribution across population categories, age groups, and HIV disease stages obtained from the 1990 to 2010 baseline simulation is used to initialize the model population at current conditions. The parameter values at the end of 2010 are then used to forecast the future of the HIV epidemic for the next 10 years. Parameter values are initially fixed at their 2010 values unless changed due to the impact of interventions or to follow pre-existing trends.

Due to the uncertainty in many of the parameter values a range in each parameter value around a fixed default value may be used in the PNG HIV model. An ensemble of parameter sets can then be sampled from these ranges using Latin Hypercube Sampling (via software such as SaSAT [9]). Each of these parameter sets can then be run through the four simulation stages described above. To generate the results in this report this option is not used and a single set of default/baseline parameter values are calibrated to match the overall population and HIV epidemiology of PNG in urban and rural settings for the 1990 to 2010 period. A detailed description of the default parameters is described in the follow sections.

Parameter Tables and Calibration to the PNG HIV Epidemic

This section describes the parameters used in the PNG HIV model, the default values used to model the HIV epidemic in urban and rural PNG, and the process used to simulate the HIV epidemic and calibrate the model to HIV epidemiology from 1990 to 2010. In particular a detailed description of all the assumptions used and the reasons for particular parameter values are provided.

Model parameters are used to describe the population demographics, sexual behaviour, HIV biology and transmission properties, and HIV clinical characteristics of the urban and rural PNG populations. The model is calibrated to available HIV epidemiology and clinical data for the period 1990 (a few years after the first recorded case in 1987 [1]) to the end of 2010 and is set to reflect the HIV epidemic in PNG for this period as best as possible. Parameter values are fixed in the model during a simulation unless they are shown to change over the 1990 to 2010 period. The final values of the parameters at the end of 2010 are used to represent current conditions for forecasting the impact of interventions. Using the model parameters described in this section the model produces the figures seen in Figures 2 and 3 in The Papua New Guinea HIV Model - Summary and Results report.

HIV epidemiology in PNG from 1990 to 2010

In this section the particular epidemiology data used to calibrate the model parameters are described. In recent years there has been a large increase in the level of HIV epidemiological data reported for PNG [1]. Despite this increase there is still a great deal of uncertainty about the HIV epidemic in PNG and a number of assumptions about the epidemic had to be made to calibrate the model. The parameters in the PNG HIV Model were calibrated so that the simulated outputs of the model for the overall PNG population best represent the epidemiological data and these assumptions. The primary source of epidemiological data were the PNG National Department of Health STI, HIV and AIDS surveillance reports (the latest of which was published in 2010 [1]), the 2007 Estimation Report on the HIV epidemic in Papua New Guinea [3], and the 2009 PNG HIV Epidemic Update which was presented at the 2009 ASHM Conference in Brisbane [2]. In addition to these sources data from biological and behavioural surveys, journal articles and other publications was obtained.

HIV Prevalence Data and Estimates

The most useful HIV epidemiological indicator for calibrating the model is HIV prevalence. There is a great deal of uncertainty surrounding the level of HIV infection in PNG. Numerous prevalence studies report a high HIV prevalence. However, studies are usually conducted at voluntary counselling and testing sites or STI clinics and the survey population is potentially at a higher risk of HIV infection than the overall population. For example in a recent biological and behavioural survey of attendees to VCT across all provinces of PNG conducted between 2003 and 2008 the HIV prevalence varied from 6.5% in Port Moresby to 0% in rural Tabibul and Wewak [10] with an overall prevalence of 1.8%. A systematic review and meta-analysis of the prevalence of HIV and other STIs in studies conducted in PNG by Vallely et al. [11] reported that in community based studies the HIV prevalence in males and females was 1.8% (calculated from four studies) and 2.59% (calculated from three studies), respectively. In clinic based studies the male HIV prevalence was 6.63% (calculated from two studies) and the female prevalence was 12.03% (calculated from two studies).

In recent years there has been a rapid expansion of testing facilities across PNG. In particular antenatal clinic (ANC) testing has expanded across the country. The recorded HIV prevalence among pregnant women tested at ANCs is generally much lower than that in reported surveys. Since 1995 the HIV prevalence amongst all pregnant women tested at ANC has risen from 0.1% to a peak of 1.3% in 2005 and then declining to 0.7% by 2009 [1] as shown in Figure 3. The reason for the peak and fall in ANC prevalence is unknown but could be due to the expansion of testing services to areas of lower HIV risk since the mid 2000s which is reflected in the number of tests that were carried out. Up to 2001 approximately 5000 ANC tests were carried out each year, this rose to 12,534 tests in 2005 and then rapidly increased to ~45,000 tests in 2008 and 2009 [1].

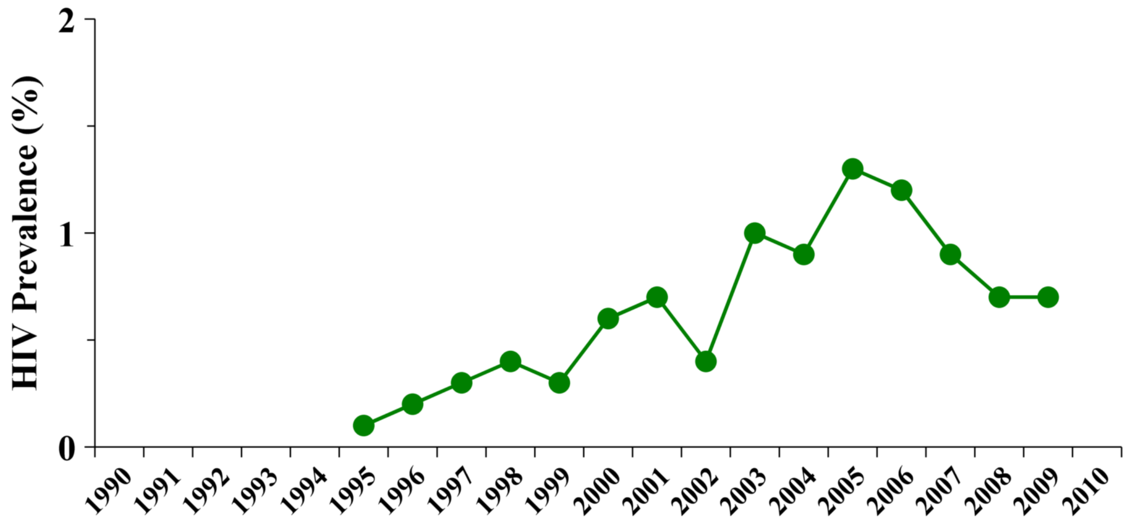


Figure 3: HIV prevalence among women at ANC in PNG from 1995 to 2009. Obtained from the 2009 STI, HIV and AIDS Annual Surveillance Report produced by NDoH [1].

Due to the broader base of testing the ANC HIV prevalence in recent years is likely to be a better reflection of the overall HIV prevalence in the adult general female population in PNG and the results from surveys are more likely to reflect HIV prevalence in at risk populations.

Collating data from antenatal clinics and other government and non-government health facilities the NDoH produces estimates of HIV prevalence in the adult population using the Estimation and Projection Package (EPP) and Spectrum software packages developed by UNAIDS [12]. Using these modelling packages estimates for the overall HIV prevalence where reported in the 2007 Estimation Report on the HIV epidemic in Papua New Guinea [3], and the 2009 PNG HIV Epidemic Update [2]. The estimates obtained are dependent on the level and quality of reporting. Due to the fall in ANC prevalence from 2005 to 2008 there was a marked difference in the 2007 and 2009 EEP estimates. In the 2007 estimates the overall prevalence was predicted to be increasing exponentially with a projected prevalence of approximately 3.5% in 2010.

However, in the 2009 estimates the estimated national prevalence has flattened to slightly less than 1%. This more recent estimate is likely to be more accurate given the higher levels of testing carried out in 2008.

Based on the ANC data and the more recent EPP estimates of HIV prevalence we assume for calibration purposes that the overall adult HIV prevalence in PNG has increased to ~1% by 2010 with some levelling off. From the biological and behavioural survey [10] and the Vallely et al. meta-analysis [11] the female population is assumed to have a higher prevalence than the male population; however, the male and female prevalence is assumed to be similar to the overall prevalence. We also assume that urban areas have a higher HIV prevalence than rural areas.

For the MSMW and FSW population groups there is less data available to estimate the HIV prevalence. The Vallely et al. meta-analysis [11] reported the HIV prevalence to be 11.76% in FSW from four published studies while a respondent driven sampling (RDS) survey of FSW in Port Moresby conducted in 2010 reported a prevalence of 19% [5]. For MSMW the only prevalence estimates found were in the UNGASS Country Progress Reports [13] which estimates the prevalence of HIV in MSM to be 4.35% but this is based on a single report from an NGO program in NCD conducted in 2009; the same NGO report estimated the FSW prevalence to be 5.86% which is much lower than other estimates for this population group. A recent RDS survey of men who sold sex to males and females in Port Moresby reported a prevalence of 8.8%. As discussed in the demographic parameters section below surveys of MSM in PNG tend to be in populations of men with high levels of sexual activity and are not likely to be representative of MSMW in PNG overall. Based on this limited data we aim to calibrate the PNG HIV model such that the HIV prevalence in MSMW is greater than the prevalence in males in the general population but less than 8% in urban areas by 2010. For FSW the HIV prevalence is calibrated to be > 10% in urban areas by 2010 and much higher than that for the general female population.

Recorded HIV Diagnoses

In Figure 4 the annual number of reported HIV cases recorded in PNG is shown. The number of diagnoses has increased substantially each year until the year 2008 after which there has been a levelling off and fall despite a large increase in the number of tests carried out [1]. The number of diagnoses in males and females are similar with slightly more females diagnosed than males particularly in recent years. The reported diagnoses of HIV are assumed to be accurate and the PNG HIV Model is calibrated to match this data as closely as possible. However, the number of diagnoses is dependent on both the number of people infected with HIV and the number of tests carried out within the population. To calibrate the model we used the prevalence and incidence projections to set the default values of the HIV transmission parameters with the diagnoses data used to calibrate the level of testing in the population.

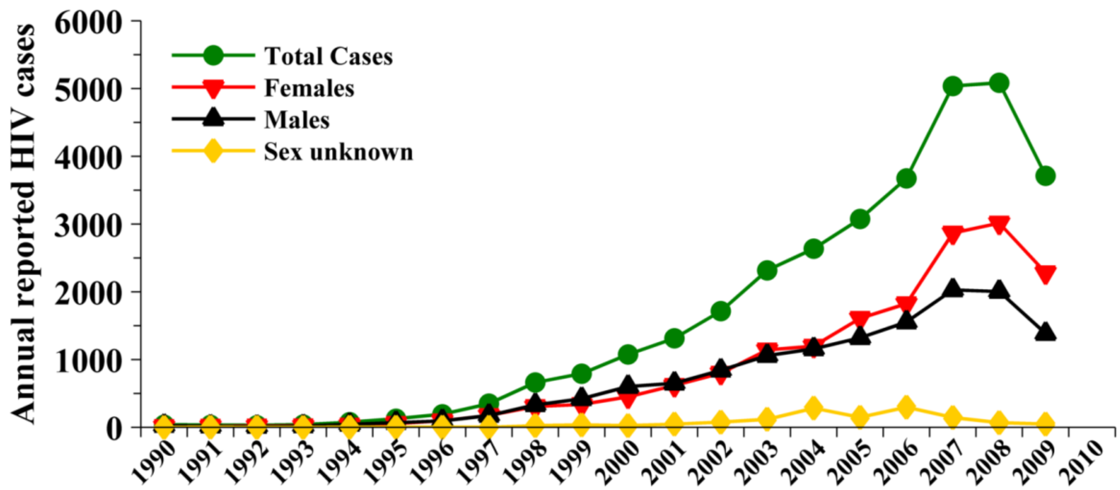


Figure 4: Number of reported HIV infections in PNG from 1990 to 2009. Obtained from the 2009 STI, HIV and AIDS Annual Surveillance Report produced by NDoH [1].

The total number of diagnoses recorded since 1990 for each age group up to the end of 2008 (when age has been recorded which has occurred in 55.39% of cases [14]) is shown in Figure 5. This figures shows that in terms of age the peak in female diagnoses occurs in females aged 20 -24 age group while the peak in male diagnoses is in the older 30-34 age group. This difference in the peak age group for diagnoses could reflect age heterogeneity in HIV incidence, age heterogeneity in HIV testing, age assortativity in sexual partnerships, or all of these factors combined (such heterogeneity has also been seen in African settings [15]). This makes it difficult to calibrate the PNG HIV model but the default parameters are calibrated to reflect this age difference in HIV diagnoses as accurately as possible.

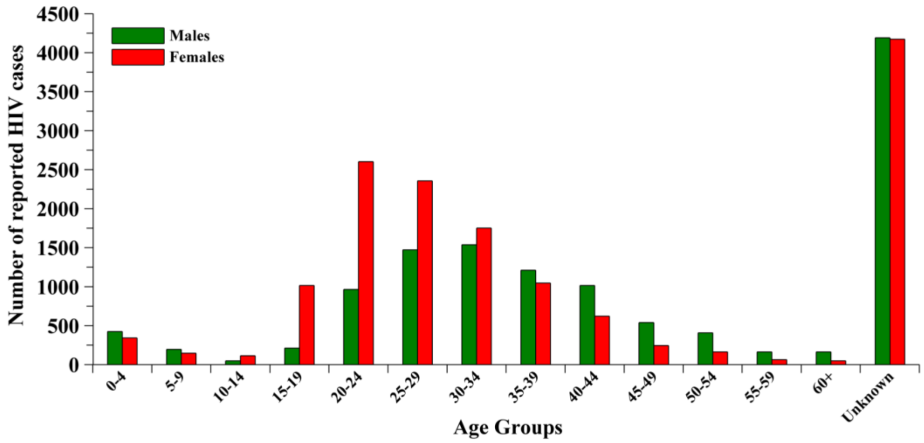


Figure 5: Age and sex distribution of cumulative HIV infections reported in PNG, 1987-2008. Data obtained from the 2008 STI, HIV and AIDS Annual Surveillance Report produced by NDoH [14].

In the majority of diagnoses the mode of HIV transmission has not been recorded or is unknown [14]. Where the transmission mode, has been recorded almost all cases are attributable to heterosexual transmission during sexual intercourse between males and females with only 0.18% of cases up 2008 and 1.7% of cases in 2009 attributed to homosexual intercourse [1, 14]. The proportion of transmissions attributed to homosexual transmission seems particularly low given the level of sexual intercourse between men (described in detail in the demographics parameters below) reported in PNG and is likely to be an under estimate. On the other hand this could also contribute to the lower than expected prevalence in MSMW described above. This low value for homosexual transmission is potentially due to high levels of discrimination and stigma towards homosexual men in PNG [6, 16] influencing the willingness of men to report that they engage in homosexual activity or possibly because the majority of MSM in PNG also report having sexual partnerships with women and specify the mode of transmission to be heterosexual. For modelling purposes we assume that is only a relatively small percentage of transmissions overall are due to homosexual transmission between MSMW to ensure the prevalence within MSMW does not become too high.

Up until 1996 the only location where voluntary counselling and testing for HIV took place was in the Port Moresby general hospital which means during the 1990s the vast majority of HIV diagnoses occurred in urban settings with people travelling to Port Moresby and other urban settings to get tested [3] or be diagnosed clinically with AIDS. Since 2004 there has been a rapid increase in the number of HIV tests carried out in PNG [1] (from 1407 recorded tests in 2004 to 123,661 in 2009 [1]). This reflects the rapid scale up of VCT and ANC testing across the country [1, 2]. In the PNG HIV model the level of testing is described by the proportion of people that get tested each year and this is calibrated to reflect the diagnosis data in Figure 4 and Figure 5 and the rapid scaling up of testing since 2004.

Roll-out of Anti-retroviral Treatment

The final HIV epidemiological indicators used to calibrate the PNG HIV model is data on ART usage by HIV positive adults and by pregnant women to prevent mother-to-child transmission (PMTCT). Since 2004 when ART became available in PNG until the end of 2009 6,323 adults have started ART [1]. The number of women who have received PMTCT is increased steadily from 100 women in 2005 to 263 women in 2009 [1]. The proportion of HIV positive pregnant women who receive PMTCT is estimated to be much lower than the required level to cover all HIV positive pregnant women [2]. The parameters describing the initiation of ART treatment in the PNG HIV Model are calibrated so that the number of people who have started treatment and the coverage of people requiring treatment reflect the rapid scale up of ART in PNG.

List of Main Assumptions about the HIV Epidemic used for Calibration

From the data described above and other available information the following general list of characteristics of the HIV epidemic in PNG were assumed to calibrate the PNG HIV Model:

- An overall adult HIV prevalence in PNG of approximately 1% by 2010
- Urban prevalence greater than the rural prevalence
- HIV prevalence in urban FSW greater than 10% by 2010
- General female prevalence greater than general male prevalence
- MSMW prevalence greater than general male prevalence but not too high
- Higher incidence in younger male and female populations
- Peak incidence in females younger than peak incidence in males
- Higher number of diagnoses in younger females
- Rapid increase in ART coverage to relatively high levels after 2003

Demographic parameters, population groups, and calibration

In this section the demographic parameter values used to model the HIV epidemic in urban and rural PNG are described. The resulting parameter values are listed in Table 2.

The size of the overall population in 1990 is based on data from the World Bank Data Catalogue [17] and the Papua New Guinea 2000 census [18]. The World Bank estimates the 1990 PNG population to be 4,131,073 people while the 1990 census recorded the total population living in PNG to be 3,607,954. The population size for 1990 in the model simulations was fixed between these two values at 3,800,000 with a population growth rate fixed and calibrated to match the population growth seen in PNG, as shown in Figure 6.

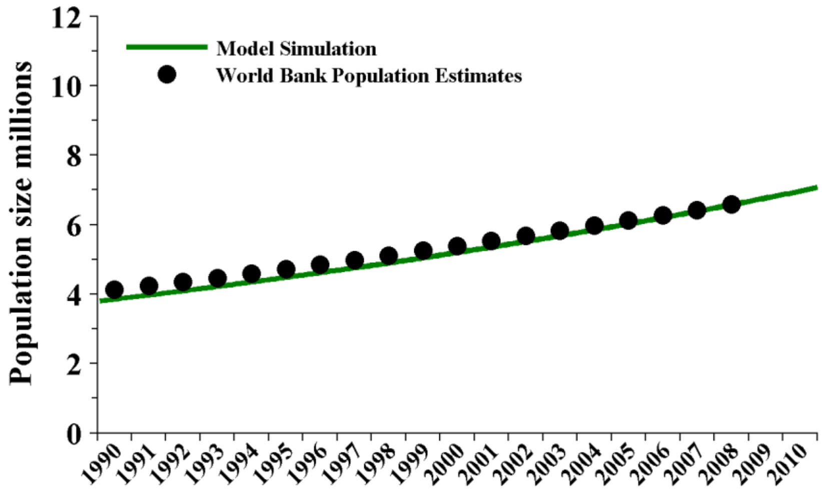


Figure 6: Overall Population Size for PNG from 1990 to 2010. This figure shows the simulated population size for the PNG HIV model from 1990 to 2010 (green line) compared to available data from the World Bank Data Bank and PNG Census data.

The overall population growth rate was based on the number of new births reproductive-aged females (assumed to be aged between 15 and 49 years) have each year. To calibrate the model we used a distribution for the proportion of babies born to mothers in each 5 year age group between 15 and 49 based on available fertility rate data for PNG [19]. This distribution is multiplied by a fixed factor that is calibrated so that the overall population size matches the World Bank and PNG census data shown in Figure 6 (the resulted birth rates are shown in Table 2).

From the PNG census conducted in the year 2000, 51.9% of the PNG population is male representing an overall sex ratio of 108 males to every 100 females [18]..This sex ratio is inconsistent with other data such as the 1990 population pyramid obtained from the US Census Bureau website which gives a sex ratio of 53.26% [20]. However, all estimates of the sex ratio for PNG show there are more males than females in the population. Despite this male majority in for modelling purposes we assume a sex ratio of 50% which simplifies the calibration of demographic characteristics and has little impact on the simulated results for the HIV epidemic in PNG.

The death rates of males and females in each age group were estimated from life tables for PNG from the World Health Organization [21]. In these life tables the death rates for each male age group is higher than for the corresponding female age group, to prevent a decreasing sex ratio over time in our model simulations (due to the assumed even sex ratio for births) we assume the same death rate for each male and female age group, equal to the mean of the male and female death rates in the life tables (Table 2). As the oldest age group in the model combines all age groups older than 60 years the value estimated from the PNG life tables is inaccurate due to the simplicity of our model. For the oldest age group the probability of death was calibrated so that the proportion of the population older than 60 years matched available population pyramid data from the US Census Bureau website [20].

The initial proportion of the overall population that is female and male in each model age group is given by the 1990 population pyramid obtained from the US Census Bureau website [20]. The evolution of the population pyramid over time depends on the birth rate, the death rates for each age group and sex, and the sex ratio of newborns. In Figure 7b the overall population pyramid at the end of the population and HIV infection set up simulation stages is shown. This is the population pyramid used to represent the overall PNG population in 1990.

The birth rates, natural death rates, sex ratio at birth and initial proportion in each age group are assumed to be the same for the urban and rural populations. The proportion of the overall population that lives in urban areas is initialized to be 14% in accordance with available estimates [17, 20, 22, 23]. The PNG Census from 2000 estimates that the proportion of people living in urban areas has decreased from ~15% in 1990 to ~13% in 2000 [20]. This agrees with the estimates from the World Bank Data Catalogue which show a decline in the proportion of the population in urban areas from 15% in 1990 to 12.54% in 2010 [17]. These decreases in the proportion living in urban areas are in contrast to anecdotal evidence and expert opinion which suggests that there is a net migration of people to urban areas (with people moving to urban areas in the search of employment amongst other reasons). However, this decrease in the urban proportion could reflect a higher birth rate in rural areas or the movement of people to large rural industrial sites (e.g. mines) which have similar characteristics to urban areas. For modelling purposes we assume the proportion of people in urban areas is fixed at 14% with migration rates calibrated to maintain this value.

(a) (b)

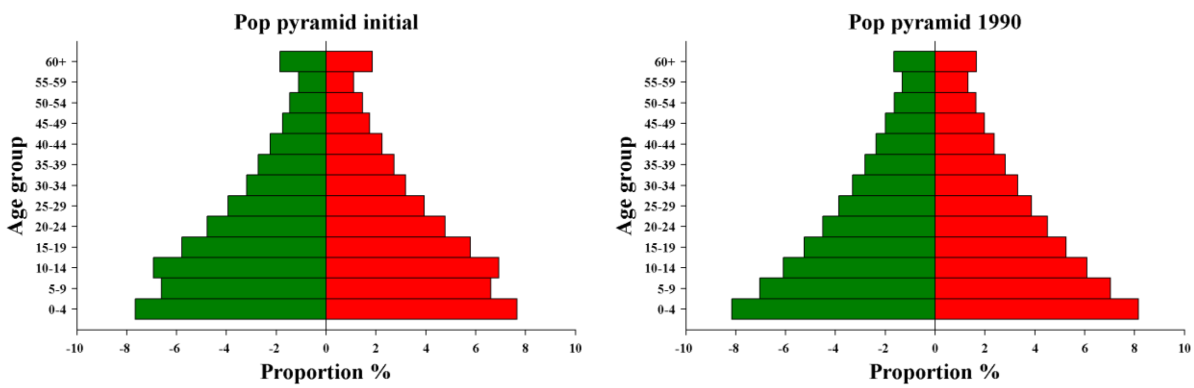


Figure 7: Initial population pyramid used to initialize the population set up simulation stage (a) and the resulting population pyramid after HIV transmission burn in period (b) which is used to represent the population in the year 1990.

Population movement within PNG is very common with people travelling regularly across the country to visit family or for employment. While the road network in PNG is limited and overland travel is often restricted to walking there is a well established airline system allowing people to travel from one side of the country to another. Despite this population movement within PNG there is no quantitative data on the number of people that move from one place to another or the time they spend in different areas. Due to this uncertainty we simply assume that 1% of people in rural areas move to urban areas each year. This value is fixed and the same for each age group. However, the results of the PNG HIV Model are sensitive to variations in the level of migration, particularly for the prevalence of HIV in FSWs. While this sensitivity has not been thoroughly investigated here, the proportion of people who migrate to urban areas can be varied using the software interface to assess the impact of migration on the PNG HIV epidemic.

For the specified rural-to-urban migration rate, the urban-to-rural migration rate is calculated so that the proportion of people in urban areas is fixed at ~14% and the proportions of men who are MSMW and women who are FSW in urban and rural populations is maintained.

Men who have sex with men and women

In the model males are divided into general males who are heterosexual and males who have sex with men and women (MSMW). The general male population is assumed to be exclusively heterosexual while the MSMW population includes men who are exclusively homosexual as well as men who very rarely engage in sexual intercourse with other men. There is a great deal of uncertainty surrounding MSMW in PNG and their sexual behaviour. Anthropological studies have reported traditional-cultural homosexual intercourse within PNG cultures [16, 24-26], however, recent surveys have found little evidence of this behaviour occurring at the present time in the wider population [16].

There is little documented data on the proportion of the overall male population that have had sex with other men and their sexual behaviour. In the few surveys carried out, a range from 0% to 15% of men interviewed reported having had sex with other men with a wide variation across occupations and location [4, 6, 7, 27, 28]. For example a behavioural surveillance survey of adult male workers recorded that 13.4% of Lae port workers, 1% of military officers, and 0% of truck drivers and Ramu sugar workers have had sex with a man [4, 7]. In another study 11.8% of male youths interviewed from the Eastern Highlands and Madang Province reported having male to male sex [16]. In terms of the sexual behaviour of MSMW there have only been a few studies in PNG specifically looking at this population.

The main study to provide quantitative information on the sexual behaviour of MSMW used respondent driven sampling to recruit and interview MSMW in Port Moresby older than 16 who have had sex with another man in the 12 months prior to being interviewed [6, 29]. Only 23% of these men identified themselves as being gay/homosexual with 10% identifying themselves to be heterosexual. This combined with the results from other surveys showed that the majority of MSMW surveyed also have sex with women (for example 75% in one survey [13]) and thus this population does not constitute a self-contained population within PNG, as is the case for homosexual/gay men in Western countries. In that study a large proportion of men interviewed had very diverse sexual networks and had bought, sold, and had sex with multiple male and female partners in the previous month: 68% had non-paying female partners, ~33% had sold sex to other men; and ~25% had sold sex to female partners [6, 29]. These results have been reinforced by a more recent study of men who sell sex in Port Moresby [5].

Such sexual behaviour implies this population of men is at high risk of acquiring HIV, however, the sampling method used does not allow an estimate of the size of this population. It is highly unlikely that the majority of MSMW in the PNG population have this level of sexual behaviour given that the estimated HIV prevalence in MSMW is 4.3% [13] and 0.18% of HIV transmissions are reported to be due to homosexual contact, where the mode of transmission has been recorded [14]. It should be noted that this mode of transmission data is likely to be inaccurate as most MSMW have sex with men and women and there are high levels of discrimination and stigma towards homosexual men in PNG [6, 16] influencing the willingness of men to report that they engage in homosexual activity.

The uncertainty in the size of the MSMW population in PNG and their sexual behaviour makes it difficult to model HIV transmission in this population and to understand its contribution to PNG HIV epidemic. The overall contribution this population makes to the overall HIV epidemic in PNG depends on the average sexual behaviour of the MSMW population (despite the likely wide variance) and the size of the population. Given the low number of recorded transmissions due to homosexual contact we assume the average number of male partners MSMW have on average is relatively low (as described in the section on sexual behaviour parameters below).

In terms of population size the data presented above suggests that 0-15% of men in PNG have had sex with another man sometime in the past. To calibrate the PNG HIV Model to the HIV epidemic we assume a proportion in the middle of this range with 6% of urban males and 4% of rural males classified to be MSMW. The higher percentage in urban areas is used to reflect the existence of a higher sexually active homosexual population in urban areas similar to the homosexual populations seen in Western Countries.

As for migration the simulated HIV epidemic is sensitive to the proportion of the male population that is MSMW. Using the software interface the proportion of men that are MSMW in urban and rural areas can be varied and the impact of the MSMW population on the HIV epidemic in PNG can be evaluated.

Circumcision

An important biomedical intervention for the prevention of HIV is male circumcision. Men with their foreskin completely removed have a ~60% reduction in the risk of acquiring HIV during vaginal sexual intercourse [30-33]. Male circumcision in PNG is more complex than in western countries where circumcision usually involves the complete removal of the foreskin when it is performed; usually soon after birth. In PNG a wide range of traditional penile cutting practices consisting of slitting or removing pieces of the foreskin occur with the foreskin rarely being removed fully [34]. These procedures can occur later in life after sexual activity has begun and be performed at home by individuals or in groups with other men [34]. Furthermore, they are likely to be less effective at preventing HIV transmission than completely removing the foreskin. In this report we reserve "circumcision" to mean the complete removal of the foreskin with "penile cutting" used to describe any slitting or partial removal of the foreskin.

There is a limited amount of quantitative data on the proportion of men who are circumcised or have undergone penile cutting in PNG with most knowledge gained through anthropological studies. In one study of 1358 adult male workers, the prevalence of circumcision was reported as 26% amongst truck drivers, 45% among rural Ramu sugar workers, 67% for military personnel, and 70% among port workers [4]; however, in this study men self reported whether they were circumcised or not and there was no information provided on level of foreskin removal required to be defined to as circumcised. There is evidence that men are circumcised just prior to or after they begin sexual activity with a study of 1701 youth in NCD reporting that 58% of sexually active youth reported being circumcised compared to 11% of the non-sexually active males [4]. Again these results could be unreliable due to self-reporting inaccuracies.

Given this lack of quantitative information it is difficult to estimate the proportion of men circumcised or with penile cutting in PNG. To calibrate the PNG HIV model to the PNG HIV epidemic we assume the same proportions of general males and MSMW are circumcised in urban and rural areas. Initially we assume men are circumcised prior to becoming sexually active, however, circumcision of older men can be implemented in the model as an intervention. In the model two types of foreskin removal are considered; penile cutting, which groups all forms of slitting and partial removal of the foreskin into one category, and circumcision which implies the complete removal of the foreskin. Available evidence suggests that only a small proportion of men are circumcised with a much larger proportion having penile cutting [34]. It is assumed that 45% of men have some form of penile cutting and 5% of men are circumcised.

Given the effectiveness of circumcision in preventing HIV, the simulated epidemic produced by the PNG HIV Model is sensitive to the proportion of men with penile cutting/circumcision and the efficacy of penile cutting in preventing HIV infection (which is assumed to be 20% given there is no data available). The proportion of general males and MSMW can be varied using the PNG HIV Model software to explore this sensitivity.

Female Sex Workers

The female population in the model is divided into general females and female sex workers (FSW). As for the MSMW population it is difficult to estimate the size of the FSW population. Furthermore, it is difficult to separate female sex workers from the general female population due to the high levels of transactional sex that occur throughout PNG; where money, goods, services, and/or protection is exchanged for sex [10, 16, 25-27]. A number of studies have reported a high percentage of males and females in PNG have engaged in transactional sex. Results from an Eastern Highlands Youth Survey reported that both married and single men and women accepted and paid for sex using cash or gifts [26]. For married men 28% had accepted cash for sex, 28% had paid cash for sex, 40% had paid gifts for sex, and 20% had paid both cash and/or gifts for sex in the previous year; the corresponding percentages for single men where 8%, 12%, 30%, and 7%, respectively. For married women 36% had accepted cash for sex, 7% had paid cash for sex, 7% had paid gifts for sex, and 2% had paid both cash and/or gifts for sex in the previous year with the corresponding percentages for single women reported as 20%, 20%, 24%, and 15%, respectively. In the 2008 UNGASS Country progress report for Papua New Guinea it was reported that 50% of married female youth and 66% of unmarried female youth reported having exchanged sex for money or favours during the previous 12 months with 28% of unmarried female youth had exchanged sex three or more times during the previous year [27]. In addition 46% of married and 42% of unmarried male youth had also engaged in transactional sex [27]. More recently a behavioural and biological survey of HIV and STIs carried out at voluntary counselling and testing sites across the whole of Papua New Guinea from 2003 to 2008 showed that a high proportion of urban and rural males and females engaged in transactional sex with 67% of rural women and 78% of rural men reported engaging in transactional sex at least once in the previous 12 months [10]; at urban sites the corresponding rates were 64% for women and 69% for men, respectively [10]. Due to the high levels of transactional sex in the general heterosexual population in PNG we have incorporated transactional sexual activity into the general male and female model population's sexual behaviour and only created a distinct female population for FSWs.

As for MSMW there have been a number of studies focused on FSW in particular settings (for example [5]). These studies tend to be limited and fail to provide estimates for the size of the FSW population in PNG. This is partly due to sex work being illegal in PNG and not brothel based as in other South East Asian Countries making it difficult to survey and estimate the size of the population. Research conducted in 1994 in the urban areas of Port Moresby, Goroka, and Lae estimated that 15,000 women were working (at least part-time) as sex workers out of a total population 315,000 people [35]. Assuming approximately 50% of the overall population is female this means approximately 9% of the female population are female sex workers at least part time. For rural areas there is no data available though it is likely that the proportion of females in rural areas who are FSW is much less than in urban settings.

The lack of data on the size of the PNG FSW population makes it difficult to model the HIV epidemic in PNG as the forecasted HIV epidemic produced by the model is highly sensitive to the FSW population size.

Given the lack of data on population size to calibrate the PNG HIV Model we assume that 5% of urban females are full-time FSW who can stop and start sex work by moving to and from the general female population. This assumption is based on the 9% figure describe above assuming most FSW work part time and that this figure is an over estimate when all of PNG's urban areas are combined. The model FSW population is also assumed to only include full time sex workers with part time sex workers treated as full time sex workers that start and stop sex work. For rural areas we assume a much smaller proportion of 1%.

In the model the proportion of females who are FSW can be age dependent with females in different age groups being more or less likely to be a FSW; for example the very young and very old females might be less likely to be sex workers. Surveys of FSW using respondent driven sampling have reported the median age of FSWs. One study of FSWs in Port Moresby and Goroka reported the median age to be 28 years and 25 years, respectively, with the predominant age group being over 30 years for Port Moresby and 20-24 years for Goroka [6, 29]. Another more recent study of FSWs in Port Moresby reported the median age to be 26 years with a mean of 28.2 years [5]. This suggests that females continue being FSW until a relatively old age. For simplicity we assume that females stop becoming FSWs once they turn 45 years of age and assume the same proportion of females are FSWs in each age group.

The proportion of females who are FSW is dependent on the duration that females engage in sex work. A number of surveys have measured the length of time since FSWs first started selling or exchanging sex [5], however, there is no data describing the total length of time that FSWs engage in sex work. To calibrate the model we adjust the rate that FSWs stop engaging in sex work so that the HIV prevalence in FSWs reflects available epidemiological data (the exact values used are shown in Table 2). The proportion of general females who then become FSWs each year is then calibrated so that the proportion of females that are FSW remains fixed at 5% in urban areas and 1% in rural areas.

Table 2: Demographic parameters for Urban and Rural PNG
Initial parameter values used to initialize the model population and to simulate the HIV epidemic in urban and rural settings in PNG. Footnotes provide details and references for the parameter values with further details in the main text. The interface column is used to record if the parameter values can be adjusted in the PNG HIV Model software interface

<table>
<tr><th>Parameter</th><th>Estimated Value</th><th>Available in GUI</th><th>Footnote</th></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">Demographic Parameters</td></tr>
<tr><td>Size of overall PNG population</td><td>3800000</td><td>Yes</td><td>d1</td></tr>
<tr><td>Proportion of overall initial population in each age group that are male and female</td><td><table>
<tr><th>Age</th><th>Male %</th><th>Female %</th></tr>
<tr><td>0-4</td><td>7.65</td><td>7.65</td></tr>
<tr><td>5-9</td><td>6.61</td><td>6.61</td></tr>
<tr><td>10-14</td><td>6.92</td><td>6.92</td></tr>
<tr><td>15-19</td><td>5.79</td><td>5.79</td></tr>
<tr><td>20-24</td><td>4.77</td><td>4.77</td></tr>
<tr><td>25-29</td><td>3.94</td><td>3.94</td></tr>
<tr><td>30-34</td><td>3.19</td><td>3.19</td></tr>
<tr><td>35-39</td><td>2.72</td><td>2.72</td></tr>
<tr><td>40-44</td><td>2.24</td><td>2.24</td></tr>
<tr><td>45-49</td><td>1.75</td><td>1.75</td></tr>
<tr><td>50-54</td><td>1.46</td><td>1.46</td></tr>
<tr><td>55-59</td><td>1.11</td><td>1.11</td></tr>
<tr><td>> 60</td><td>1.85</td><td>1.85</td></tr>
</table></td><td>No</td><td>d2</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Sex ratio at birth (proportion of babies that are born male)</td><td>50%</td><td>No</td><td>d3</td></tr>
<tr><td>Birth rate (percentage of females in each group who give birth each year)</td><td>
<table>
<tr><th>Age</th><th>Birth-rate %</th></tr>
<tr><td>0-4</td><td>0</td></tr>
<tr><td>5-9</td><td>0</td></tr>
<tr><td>10-14</td><td>0</td></tr>
<tr><td>15-19</td><td>7.48</td></tr>
<tr><td>20-24</td><td>24.04</td></tr>
<tr><td>25-29</td><td>23.92</td></tr>
<tr><td>30-34</td><td>20.34</td></tr>
<tr><td>35-39</td><td>14.61</td></tr>
<tr><td>40-44</td><td>7.94</td></tr>
<tr><td>45-49</td><td>3.57</td></tr>
<tr><td>50-54</td><td>0</td></tr>
<tr><td>55-59</td><td>0</td></tr>
<tr><td>> 60</td><td>0</td></tr>
</table>
</td><td>No</td><td>d4</td></tr>
<tr><td>Proportion of males and females in each 5 year age group who die before moving to the next age group.</td><td>
<table>
<tr><th>Age</th><th>Male %</th><th>Female %</th></tr>
<tr><td>0-4</td><td>7.32</td><td>7.32</td></tr>
<tr><td>5-9</td><td>0.761</td><td>0.761</td></tr>
<tr><td>10-14</td><td>0.54</td><td>0.54</td></tr>
</table>
</td><td>No</td><td>d5</td></tr>
</table>

<table>
<tr><td></td><td>
<table>
<tr><td>15-19</td><td>0.945</td><td>0.945</td></tr>
<tr><td>20-24</td><td>1.36</td><td>1.36</td></tr>
<tr><td>25-29</td><td>1.542</td><td>1.542</td></tr>
<tr><td>30-34</td><td>1.91</td><td>1.91</td></tr>
<tr><td>35-39</td><td>2.513</td><td>2.513</td></tr>
<tr><td>40-44</td><td>3.281</td><td>3.28</td></tr>
<tr><td>45-49</td><td>4.45</td><td>4.45</td></tr>
<tr><td>50-54</td><td>6.2</td><td>6.2</td></tr>
<tr><td>55-59</td><td>8.849</td><td>8.849</td></tr>
<tr><td>> 60</td><td>47.5*</td><td>47.5*</td></tr>
</table>
</td><td></td><td></td></tr>
<tr><td>Proportion of the population living in urban areas</td><td>14%</td><td>Yes</td><td>d6</td></tr>
<tr><td>Proportion of urban males that are MSMW</td><td>6%</td><td>Yes</td><td rowspan="2">d7</td></tr>
<tr><td>Proportion of rural males that are MSMW</td><td>4 %</td><td>Yes</td></tr>
<tr><td>Proportion of urban and rural males in each age group that undergo penile cutting and circumcision each year</td><td>
<table>
<tr><th rowspan="2"></th><th colspan="2">Urban Areas</th><th colspan="2">Rural Areas</th></tr>
<tr><th>Penile Cutting %</th><th>Circumcision %</th><th>Penile Cutting %</th><th>Circumcision %</th></tr>
<tr><td>At</td><td>45</td><td>5</td><td>45</td><td>5</td></tr>
</table>
</td><td>Yes</td><td>d8</td></tr>
</table>

<table>
<tr>
<td></td>
<td>
<table>
<tr><td>Birth</td><td></td><td></td><td></td><td></td></tr>
<tr><td>All other age groups</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>
</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of females in urban and rural areas that are FSWs (equal to the initial proportion in each age group)</td>
<td>
<table>
<tr><th>Age</th><th>Urban %</th><th>Rural %</th></tr>
<tr><td>0-4</td><td>0</td><td>0</td></tr>
<tr><td>5-9</td><td>0</td><td>0</td></tr>
<tr><td>10-14</td><td>0</td><td>0</td></tr>
<tr><td>15-19</td><td>5</td><td>1</td></tr>
<tr><td>20-24</td><td>5</td><td>1</td></tr>
<tr><td>25-29</td><td>5</td><td>1</td></tr>
<tr><td>30-34</td><td>5</td><td>1</td></tr>
<tr><td>35-39</td><td>5</td><td>1</td></tr>
<tr><td>40-44</td><td>5</td><td>1</td></tr>
<tr><td>45-49</td><td>5</td><td>1</td></tr>
<tr><td>50-54</td><td>0</td><td>0</td></tr>
<tr><td>55-59</td><td>0</td><td>0</td></tr>
<tr><td>> 60</td><td>0</td><td>0</td></tr>
</table>
</td>
<td>Yes</td>
<td>d9</td>
</tr>
<tr>
<td>Proportion of FSW who stop engaging in sex work in year</td>
<td>
<table>
<tr><th>Age</th><th>Urban</th><th>Rural</th></tr>
</table>
</td>
<td>Yes</td>
<td>d10</td>
</tr>
</table>

<table>
<tr>
<td></td>
<td>
<table>
<tr><td>0-4</td><td>0</td><td>0</td></tr>
<tr><td>5-9</td><td>0</td><td>0</td></tr>
<tr><td>10-14</td><td>0</td><td>0</td></tr>
<tr><td>15-19</td><td>0.05</td><td>0.05</td></tr>
<tr><td>20-24</td><td>0.05</td><td>0.05</td></tr>
<tr><td>25-29</td><td>0.05</td><td>0.05</td></tr>
<tr><td>30-34</td><td>0.05</td><td>0.05</td></tr>
<tr><td>35-39</td><td>0.05</td><td>0.05</td></tr>
<tr><td>40-44</td><td>0.05</td><td>0.05</td></tr>
<tr><td>45-49</td><td>1</td><td>1</td></tr>
<tr><td>50-54</td><td>1</td><td>1</td></tr>
<tr><td>55-59</td><td>1</td><td>1</td></tr>
<tr><td>> 60</td><td>1</td><td>1</td></tr>
</table>
</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of males and females who migrate rural to urban areas each year</td>
<td>
<table>
<tr><th>Population Group</th><th>From Rural to Urban Areas</th></tr>
<tr><td>General males</td><td>1%</td></tr>
<tr><td>MSMW</td><td>1%</td></tr>
<tr><td>General females</td><td>1%</td></tr>
<tr><td>FSW</td><td>1%</td></tr>
</table>
</td>
<td>Yes</td>
<td>d11</td>
</tr>
</table>

d1: As explained in the main text the size of the sexually active population size in 1990 was assumed to be between the values from the World Bank and the 2000 PNG census [17, 18]. From the initial 1990 population the growth rate (which is assumed to be the same for urban and rural areas and described in d2 below) was set to match the growth of the 15-49 year old population seen in PNG from 1990 to 2008 [17, 18].

d2: As described in the main text these population proportions are based on the population pyramid obtained for PNG from the US Census Bureau website [20].

d3: This value is an assumption as discussed in the main text.

d4: As discussed in the main text the proportion of females who give birth each year is calibrated to match the growth rate seen in PNG from 1990 to 2010. The distribution across age groups is based on data from the 2006 Demographic and Health Survey in PNG [19].

d5: These death rates were estimated from life tables for PNG available from the World Health Organization [21]. * The probability of death for people older than 60 years was calibrated so that the proportion of the population older than 60 years matched available population pyramid data from the US Census Bureau website [20] as described in the main text.

d6: This proportion is based on data from the 2000 PNG Census and the World Bank Data Catalogue [17, 18].

d7: The proportion of men that are MSMW is discussed in detail in the main text.

d8: The proportion of men that are have penile cutting or are circumcised is discussed in detail in the main text. It is likely that PNG men are circumcised after birth or after they become sexually active but it is assumed in the model that men are only circumcised at birth prior to becoming sexually active.

d9: The proportion of females who are FSW is discussed in detail in the main text.

d10: The proportion of FSW who stop sex work and return to the general female population is calibrated to maintain the proportion of females who are sex workers in d11. FSW older than 45 are assumed to rapidly stop sex work.

d11: As discussed in the main text the rural to urban migration rates are assumed to be 1% for each population category and the urban to rural rates are then calibrated so that the proportion of the population in urban areas remains fixed overall and the proportion of MSMW and FSW in urban and rural areas also remains fixed.

Baseline HIV Biology and Transmission Parameters

In this section the parameters and assumptions used to describe the underlying biology of HIV transmission and disease progression are described. These are listed in Table 3. The majority of these parameters are informed by biomedical and clinical data obtained from international studies and are standard for models of HIV transmission. This means the parameters in Table 3 are generally independent of the population characteristics of PNG and have been obtained from available literature. However, there are two parameters that are dependent on the sexual behaviour within the PNG population; these are the reference probability of HIV transmission and the prevalence of sexually transmitted disease in each population group.

The reference probability of HIV transmission is the probability per sexual act that a HIV positive person not on ART in the chronic stage of HIV infection transmits HIV to their negative partner, assuming neither partner is infected with another STI. Three reference transmission probabilities are used in the PNG HIV model representing transmission during sexual intercourse from males to females, from females to males, and between males during anal sex. These probabilities are based on estimates of the per-act transmission probability from cohort studies of heterosexuals in Africa [36-39] and homosexuals in high income countries [40].

These estimates are likely to be similar for vaginal and anal intercourse transmission in PNG as the main HIV subtype in PNG is subtype C which is the dominant subtype in Africa [41]. However, there are two factors that could result in a higher male to female transmission probability in PNG. These are heterosexual anal sex and sexual violence. There is evidence that heterosexual anal sex is relatively common in PNG. For example 20% of females have reported ever having had anal sex [27] and 63% of FSWs have practised penile-anal intercourse [42]. Unfortunately, the frequency of heterosexual anal sex and the proportion of people who engage in it regularly have not been measured so this behaviour cannot be directly incorporated into the model. However, the practise of heterosexual anal sex can be simplistically incorporated into the model by increasing the male to female per-contact HIV transmission probability.

Sexual violence is also common in PNG with numerous studies from across the country reporting large proportions of women that have been forced to have sexual intercourse or have been gang raped; furthermore a large percentage of men report being involved in sexual violence [5, 6, 10, 16, 26]. In one behavioural and biological survey conducted at 12 urban and rural sites across PNG between 26.7% and 80.2% of women had been forced to have sexual intercourse [10]. The majority of sexual abuse has been reported to occur most frequently within marriage or intimate partner relationships (classified as regular partnerships in the model) [16]. Women engaged in transactional sex or female sex work are particularly vulnerable to sexual violence with 50% of FSW in Port Moresby reporting they experienced forced sex in the last 6 months in a recent survey [5]. In terms of HIV transmission there is a significant association between sexual violence and HIV infection for women with those reporting sexual abuse being twice as likely to be HIV positive to those who report no sexual abuse [43]. However, changes to the underlying reference HIV transmission probability from males to females are unknown and difficult to determine so the affect of sexual violence can only be incorporated in the model simplistically by increasing the male to female per-contact HIV transmission probability. The default values of the transmission probabilities used in the PNG HIV model are shown in Table 3 these have been calibrated to match the available HIV prevalence estimates for PNG.

Another factor affecting HIV transmission is the presence of other sexually transmitted infections. Numerous studies have shown an association between being infected with a STI other than HIV and the risk of acquiring HIV [39]. This is particularly true for ulcerating infections such as syphilis and HSV-2. However, clinical trials investigating the impact of reducing STI prevalence have shown there is no effect on HIV incidence suggesting that other STIs may not increase the probability of HIV transmission as much as thought [44-46]. In the PNG HIV model the estimated prevalence of other STIs is used to determine the probability that at least one partner within a sexual partnership has an STI. The baseline HIV transmission probability is then adjusted by a multiplicative factor to account for the presence of an STI.

Numerous STI prevalence surveys have been conducted in PNG and these have recently been collated in a systematic review and meta-analysis [11]. In this meta-analysis studies estimates for the prevalence of bacterial vaginosis, Chlamydia, HSV-2, gonorrhoeae, syphilis, and Trichonomonas within surveys of males and females in community and clinic based settings and FSWs were estimated. Some important differences were found between urban and rural populations with rural areas generally having a higher STI prevalence than urban areas. This is particularly true for HSV-2 with estimates among rural men varying between 27 and 33% compared to ~8% in Port Moresby. For the PNG HIV model we focus on the ulcerating STIs such as syphilis and HSV-2. For males syphilis prevalence ranged from 3.7% to 12.88% with an overall prevalence in clinic based studies of 5.03% (95% CI 2.9% to 7.16%) and the 12.88% prevalence coming from the only community based study analysed. The prevalence of HSV-2 in males varied from 8.20% to 33.13% in community based studies with an overall prevalence estimated to be 22.77% (95% CI 4.91% to 40.64%) and there were no clinic based HSV-2 prevalence estimates reported. Syphilis prevalence in females varied from 3.98% to 16.67% with an overall prevalence of 7.92% (95% CI 0.77% to 15.07%) in community based studies and an overall prevalence of 7.86% (95% CI 3.64% to 12.07%) in clinic based studies. The overall HSV-2 prevalence for females in community based studies was 18.39% (95% CI 4.96% to 31.83%). As expected the prevalence of syphilis and STIs is much higher in FSWs with the syphilis prevalence ranging between 22.09% and 41.76% in FSWs with an overall prevalence of 31.14% (95% CI 26.33% to 52.27%).

Focusing on the syphilis results, we assume the STI prevalence for each population group in the PNG HIV model to be: 5% in urban general males; 6% in urban MSMW; 8% in urban general females; and 30% in urban FSW. A higher average prevalence for MSMW is assumed due to their higher sexual behaviour. For rural areas we assume a slightly higher STI prevalence as shown in Table 3. For modelling purposes these values are assumed to be the same for all age groups; in any case there is insufficient data to obtain age-specific prevalence. In terms of time trends the limited number of studies for each STI reviewed by Vallely et al. [11] and the uncertainty for most of the studies is too high for any time trends to be obtained. Thus we also assume that the STI prevalence for each population group is fixed over the 1996 to 2010 period.

Mother-to-child transmission

The PNG HIV Model also includes mother to child transmission. The probability that a HIV positive pregnant woman transmits HIV to her child (during pregnancy, child birth, or through breast feeding) is determined from international studies of mother to child transmission [47-51]. In PNG it is likely that most children are breast feed for extended periods so we set the reference transmission probability to 41% [49]. To estimate the impact of impact of prevention of mother-to-child therapies (PMTCT) or being on ART in reducing the risk of transmission to infants we used results from clinical trials [52]. For PNG we assumed that PMTCT for women not on ART involved a single dose of Nevrapine which results in a ~42% reduction in mother-to-child transmission [47, 52]. For HIV positive pregnant women taking ART the reduction in transmission probability is substantially greater at 98% [53]. The coverage of PMTCT in urban and rural areas is discussed in the section on clinical parameters below.

Table 3: Parameter Table for HIV Biology and Transmission Parameters
Parameter values used to describe the biological transmission and disease progression characteristics of HIV. These parameters are used to simulate the transmission of HIV between populations and to describe the disease progression of infected individuals. The value of each of these parameters is fixed over time. Footnotes provide details and references for the parameter values used with further details in the main text.

Parameter Description	Estimated Values		Available in GUI	Footnote
HIV transmission				
Per-act reference transmission probability from chronically infected females to males during unprotected sexual intercourse		0.00052	Yes	c1
Per-act reference transmission probability from chronically infected males to females during unprotected sexual intercourse		0.002		
Per-act reference transmission probability from chronically infected males to males during unprotected anal intercourse		0.008		
Multiplicative factor for the change in reference HIV transmission probability due to stage of HIV infection	Undiagnosed Primary	9.2	No	c2
	Undiagnosed Chronic	1		
	Undiagnosed Late HIV/AIDS	7.3		
	Diagnosed Primary	9.2		

	Diagnosed Chronic	1		
	Diagnosed Late HIV/AIDS	7.3		
	First line ART	0.1		
	First line ART Failure	1		
	First line ART	0.1		
	First line ART Failure	1		
Efficacy of condoms		95%	No	c3
Reduction in HIV acquisition for circumcised general males and MSMW through vaginal intercourse		60%	No	c4
Reduction in HIV acquisition for general males and MSMW with penile cutting/slitting through vaginal intercourse		20%	Yes	
HIV progression and death rates				
Pre year death rate due to HIV infection for each infection stage per year			No	c5
	Undiagnosed Primary	0		
	Undiagnosed Chronic	0.03		
	Undiagnosed Late HIV/AIDS	0.5		
	Diagnosed Primary	0		
	Diagnosed Chronic	0.03		
	Diagnosed Late HIV/AIDS	0.5		
	First line ART	0.04		
	First line ART Failure	0.3		

<table>
<tr>
<td></td>
<td><table><tr><td>First line ART</td><td>0.04</td></tr><tr><td>First line ART Failure</td><td>0.3</td></tr></table></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average time to progress from primary HIV infection to chronic HIV infection</td>
<td>6 months</td>
<td rowspan="2">No</td>
<td rowspan="2">c6</td>
</tr>
<tr>
<td>Average time to progress from chronic HIV infection to AIDS</td>
<td>8 years</td>
</tr>
<tr>
<td colspan="4">STI Prevalence</td>
</tr>
<tr>
<td>Prevalence of sexually transmitted infections other than HIV in each population group</td>
<td><table><tr><th>Population group</th><th>STI Prevalence</th></tr><tr><td>Urban general males</td><td>5%</td></tr><tr><td>Urban MSMW</td><td>6%</td></tr><tr><td>Urban general females</td><td>7%</td></tr><tr><td>Urban FSW</td><td>30%</td></tr><tr><td>Rural general males</td><td>7%</td></tr><tr><td>Rural MSMW</td><td>8%</td></tr><tr><td>Rural general females</td><td>9%</td></tr><tr><td>Rural FSW</td><td>32%</td></tr></table></td>
<td>Yes</td>
<td>c7</td>
</tr>
<tr>
<td>Multiplicative factor for the increased HIV transmission probability due to the presence of another STI</td>
<td>5</td>
<td>No</td>
<td>c8</td>
</tr>
</table>

Mother-to-Child Transmission			
Overall mother-to-child transmission probability during pregnancy and breast feeding assuming no intervention	0.41	Yes	c9
Efficacy of PMTCT measures for HIV positive pregnant women not on ART	0.5	Yes	c10
Efficacy of ART in preventing mother-to-child transmission	0.98	No	
c1: The per-act contact rates for male to female, female to male, and male to male transmission are based on numerous studies [36-40, 54, 55] and represent the probability of HIV transmission from an infected partner who is in the chronic infection stage and not on ART during a sexual act with neither partner infected with other STIs [39]. A recent systematic review and meta-analysis of the per sexual act found that for western populations the female to male probability of transmission was 0.0004 with a 95% confidence interval 0.0001-0.0014 and the male to female transmission probability was 0.0008 with a 95% confidence interval 0.0006-0.001 [39]. When the analysis was applied to low income populations (like PNG) the female to male and male to female HIV transmission probabilities where very similar and much higher; 0.0038 and 0.003, respectively [39]. These higher probabilities are likely to be due to the higher levels of STI infection, in particular genital ulcer disease, in low income settings. Hence we base our heterosexual transmission probabilities on the values for western countries and adjust these values using a multiplicative factor if an STI is present. For male to male transmission during anal sex our baseline HIV transmission probability was based on an early estimate of 0.0082 (95% CI 0.0024-0.0276) [54] which is comparable to the results found in a more recent study which characterised transmission by sexual position and circumcision status [40]. The values we use here have been calibrated to match the HIV epidemiology data for PNG while remaining in the reported confidence intervals for the per act transmission probabilities. One exception to this, described in the main text, is that we allow the male to female transmission probability to be higher to take into			

account the level of anal sex and sexual violence that are present in PNG [10, 16, 26].

c2: The per act transmission probability is dependent on the disease stage and characteristics of the infected partner. In the model this change in transmission probability is incorporated using a multiplicative factor. The infectiousness of HIV is higher during the early primary stages of infection and during the late stages when AIDS develops. A number of studies have estimated the relative increase in transmission probability for early and late stages of infection. These have been reviewed and combined in a meta-analysis [39] which found the per act transmission probability when the infected partner is in the primary stage of HIV is 9.17 times as infectious as someone in the asymptomatic/chronic stage. For late HIV infection the an infected partner was estimated to be 7.27 times as infectious [39]. It is well known that infected individuals on effective ART have a low probability of transferring HIV to their partners [36-38]. We assume a 90% reduction in transmission probability for people on effective ART which is consistent with reductions found in heterosexual couples [38]. We assume the same reduction for anal intercourse between men as there have been no studies explicitly looking at the transmission within discordant homosexual couples where the infected partner is on effective ART. We assume the same reduction for both first line and second line ART regimes. Finally, infected individuals with virological failure are assumed to have the same infectiousness as HIV positive people in the chronic stage.

c3: This is based on estimates of condom efficacy [56, 57].

c4: The protective effect of complete foreskin removal is estimated from the results of a number of random control trials evaluating the impact of circumcision of HIV transmission [30-32]. For penile cutting and the partial removal of the foreskin there is no data available on the relative effectiveness in reducing the risk of HIV acquisition but it is likely to vary widely depending on the level of foreskin removal. Due to this lack of data in the model we simply assume a 20% reduction for men who have any penile cutting. This value can be changed in the model software interface when more accurate information becomes available.

c5: The rate that individuals die due to their HIV infection, in addition to the natural death rate, is dependent their stage of infection and is based on available clinical data [58, 59]. We assume people with AIDS and that have failed ART have the same death rate. The death rates for people with AIDS correspond to an approximate 2 year life expectancy.

c6: These estimates are based on available clinical data [60-63] . In the model these time periods are represented as rates that are equal to the inverse of these time periods.

c7: The STI prevalence for each population is described in detail in the main text. The prevalence of STIs in each population group is fixed over time and have been calibrated to the HIV epidemic in PNG from 1990 to 2010 the PNG HIV model.

c8: This multiplicative increase in HIV transmission probability if one partner in a discordant partnerships has an STI is based on the estimates for genital ulcer disease in the Boily et al. meta-analysis [39].

c9: The parameters describing mother-to-child transmission are described in the main text. The probability of mother to child transmission is assumed to be the same for all HIV positive pregnant women not taking effective ART and combines the probability of transmission during pregnancy and the probability of transmission through extended breast feeding [47, 49].

c10: The efficacy of PMTCT is based on the once of use of Nevrapine [47, 52]. If HIV positive pregnant females are using effective ART for their infection then the probability of transmission to their child is substantially reduced [53].

Baseline Sexual Behaviour Parameters

Parameters and assumptions used to characterise the sexual behaviour of the PNG population are described in this section with the final parameter values listed in Table 4. In the model we assume females in the population become sexually active when they turn 15 years of age which is consistent with available data, where the age of sexual debut which tends to be reported as 16 to 17 years of age [6, 10]..

For the PNG HIV model the most important parameters are the average number of sexual partners each individual has per year and the level of condom usage in the population. Partner numbers for each population group are divided into casual and regular partners and can vary across age groups and over time. In addition age differences in partnerships between males and females are incorporated. Unfortunately the data available on the number of annual partners for individuals in PNG is limited meaning a number of assumptions have to be made to fill in missing or unreliable data. A detailed description of the sexual partner and condom usage parameters and assumptions used in the model are described in detail in separate sections below.

Condom usage for each population group

Condoms are an effective way of preventing the transmission of HIV and other STIs. The preventative effect of condoms is incorporated in the model by estimating the proportion of sexual acts where a condom is used (or probability of condom use) and adjusting the probability of HIV transmission assuming that condoms have an efficacy of 95%. The model describes casual and regular partnerships between: general males and general females; general males and FSWs; MSMWs and general females; MSMWs and FSWs; and between MSMWs.

Estimates of condom usage for each type of partnership are based on the available data obtained from surveys of population groups in PNG. In these surveys a number of measures are used to record condom use, such as the proportion of the population who have never used a condom, always use condoms, or consistently use condoms over a certain time period. The most useful measure for modelling purposes is the proportion/probability of condom use at last act which is what will be focused on here. However, other measures of condom use are useful for giving an upper or lower bound on this probability. Note that since a condom is used during an act between two people in different population categories the proportion of sexual acts protected by condoms for each population group will be the same for that type of partnerships; however, this may not be shown in behavioural surveys due to inherent measurement bias.

In PNG knowledge of condoms is generally high but the use of condoms in the general population tends to be low and inconsistent with many studies reporting a high proportion of people having never used a condom including those that are HIV positive [16]. Sexual behavioural surveys in the PNG population are generally focused on population groups at risk of HIV such as FSWs, MSMWs, and males in particular employment groups and are generally done in urban settings [16]. Additionally most of these surveys have been conducted since 2005 and are often in small specific populations. This means it is difficult to estimate the per act condom usage for each type of partnership and the time trends from 1990 to 2010. For each type of partnership we show all the available estimates for the proportion of last acts protected with a condom over time. We then estimate the probability of condom use from 1990 to 2010 for each type of partnership in rural and urban settings. In general there is very little data for partnerships in rural areas; however, a few reports suggest that sexual behaviour between males and females is similar in both settings [26]. Nevertheless we expect condom use to be less in rural areas, mainly due to a lack of availability and lower knowledge, and assume that condom use is a certain percentage less than in urban areas unless there is evidence to the contrary.

The condom values used in the PNG model are based on the actual values and trends in condom usage reported. For all population groups we assumed that the condom usage in rural areas followed the same trends over time as urban populations but have a 50% lower value due to lack of access to condom supplies. In all cases we fit the same simple function to the available data values. This function starts at a low constant value from 1990 to 1995 before beginning to rise linearly to a potentially higher value in 2005 before levelling off towards 2010. Examples of this fitting function can be seen in Figure 8 and Figure 10.

General Male and General Female Partnerships

Self reported values for condom use at last act from surveys of males and females in the general population were used to estimate condom usage in casual and regular partnerships between general males and general females. Data values for casual partnerships include transactional (non-commercial) relationships. All of the values obtained and the corresponding survey year are shown in Figure 8 and were obtained from numerous sources [4, 10, 13, 25, 27, 64-67].

These values were obtained from volunteer behavioural surveys of men or women at VCT, ANC clinics, or STI clinics. Surveys have mostly focused on youths or males with careers thought to be at risk of HIV such as truck drivers, port workers, plantation workers, petroleum workers, and military offices. The majority of values used are from time periods since 2003 and for casual or transactional (non-commercial) partnerships. The few values for condom use during the 1990s tended to be very low [25]. Only a few values were obtained for rural populations which generally had lower condom use than urban populations. This was particularly true for two studies in 1995 where only 5-7% of women reported having ever used a condom [64, 65].

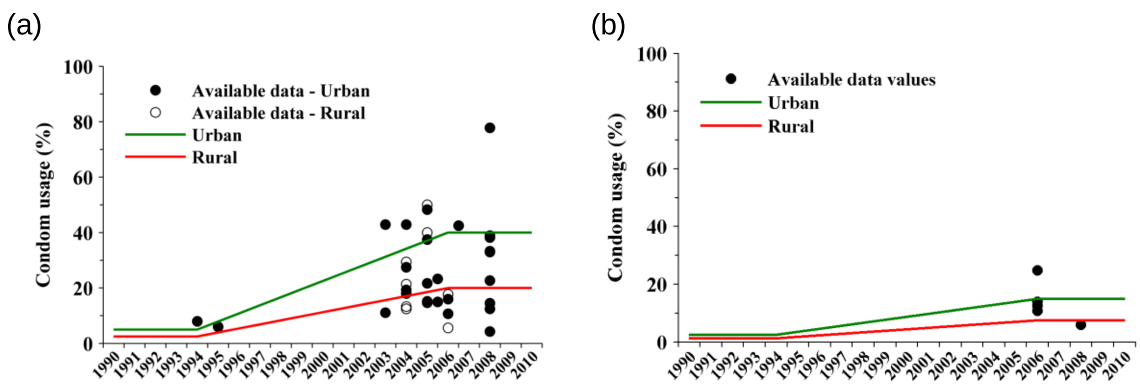


Figure 8: Condom usage over time for (a) casual and (b) regular partnerships between general males and general females. The dots represent available data values while the lines represent the default values used in the PNG HIV Model. Data values can be from distinct methodologies and represent condom use at last sex or based on self-reported values of consistency of condom use over a certain time period, hence they should not be compared directly but are used to indicate the level of condom use.

Generally there is a large variation in condom usage values across surveyed populations. For example a recent biological and behavioural survey of attendees to VCT across all provinces of PNG conducted between 2003 and 2008 reported that 5.6% to 50% of males and females reported using a condom during their last sex act. There was a wide variation across the sexes and across the sites though females generally reported higher condom usage than males at each site and urban areas generally had higher levels of condom use than rural areas [10]. As shown in Figure 8 there are very few data values for regular partnerships. All of these values were from surveys since 1995 and were generally very low (< 20%). From one bio-behavioural survey of ANC clients in Port Moresby conducted during 2008, 94% of women did not use a condom at last sex with their regular partners and only 5% reported they had used a condom at last sex with their husband [67].

Based on the condom usage data presented in Figure 8 we assumed a simple increase in condom usage over time from a low value in 1990. For casual partnerships in urban areas 5% of sexual acts were protected with condoms in 1990 which means a value of 2.5% for rural areas under our assumptions. This condom usage was assumed to be constant until 1995 before rising linearly to a level of 40% and 20% during the 2006 to 2010 period in urban and rural areas respectively. The condom usage level for regular partnerships is assumed to be half that of the casual partnership value.

General Male and FSW Partnerships

Condom use in sexual partnerships between general males and FSW was estimated from surveys of FSWs and males who engage in sex work. Casual partnerships included partnerships with commercial clients as well as with non-paying partners.

Often these values were obtained from male population groups in professions at risk of HIV infection (Truckers, Dock Workers, Sailors, Police, and Security workers), women attending STI clinics, or from respondent driven sampling (RDS) of FSW in Port Moresby, Goroka, Lae and along the Highlands Highway. All of the values and the corresponding survey year are shown in Figure 9 and were obtained from [3, 4, 6, 13, 27, 29, 35, 42, 66, 68]. Generally there is a large variation in condom usage values across surveyed populations. However, as seen in Figure 9 there is an increasing trend from lower values for casual/commercial partnerships in the early 1990s to much higher levels in the last decade.

(a) (b)

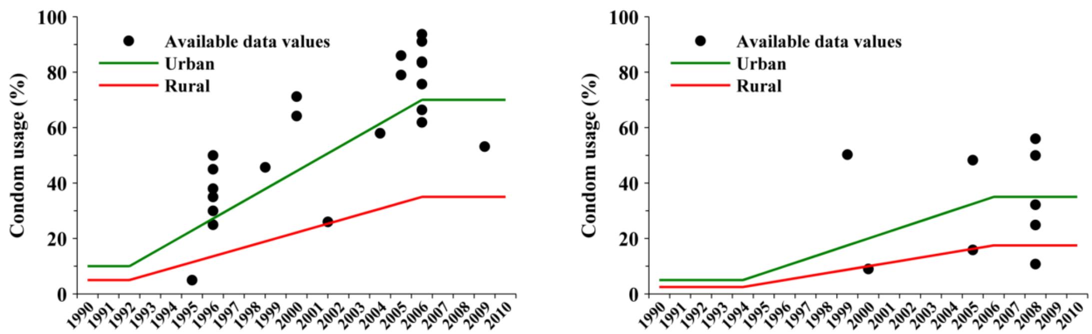


Figure 9: Condom usage over time for (a) casual and (b) regular partnerships between general males and FSW. The dots represent available data values while the lines represent the default values used in the PNG HIV Model. Data values can be from distinct methodologies and represent condom use at last sex or based on self-reported values of consistency of condom use over a certain time period, hence they should not be compared directly but are used to indicate the level of condom use.

There are fewer data values for condom usage between FSW and their regular male partners (Figure 9). The values vary between 9% and 56% and are higher than condom usage in casual partnerships between general males and general females. Unlike casual partnerships there is no apparent trend over time but we still assume a much lower value for the 1990 to 1995 period.

For commercial or client partnerships between FSW and males in urban areas we assume a condom usage of 10% between 1990 and 1992 before a rapid rise up to 70% during the 2006 to 2010 period. The condom usage level for regular partnerships between FSW and males is assumed to be half that of the corresponding casual partnership value. For urban areas this usage level rises to 40% for the 2006 to 2010 period.

MSMW and MSMW Partnerships

There is very little information on condom usage during anal sex in partnerships between men. All the data values found are shown in Figure 10 and were obtained from urban settings and are for casual, transactional, or commercial partnerships [3, 6, 13, 27]. The vast majority of data values come from RDS surveys of MSM in Port Moresby [6]. The population in this survey is highly sexually active with a high proportion buying and selling sex to both males and females [6]. The only data available for no condom usage in regular partnerships between men was for regular male commercial clients [6] with 45.6% to 50% of men using condoms during their last act with regular male clients [3, 6].

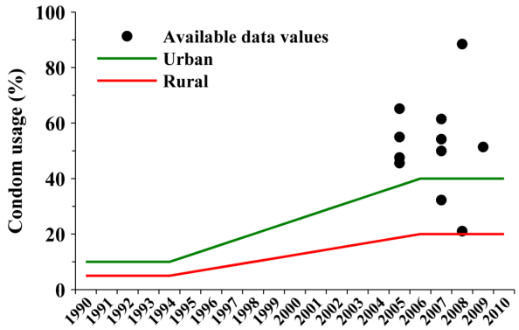


Figure 10: Condom usage over time for partnerships between MSMW and MSMW.

Since the available condom use data for partnerships between MSMW (as shown in Figure 10) is from a population of highly sexually active men we assume that the condom usage values obtained from these reports are over estimates for the overall MSMW population. In urban areas we assume the condom usage is initially 10% for casual partnerships between MSMW in 1990. Over time this rises to 40% by 2010 as shown in Figure 10. Again we assume that the condom usage in rural areas is 50% of that in urban areas. None of the data obtained for MSMW described condom usage within regular partnerships so it is assumed that the condom usage in these partnerships is the same as for regular partnerships between general females and males.

MSMW and Female Partnerships

The only data available for MSMW and female partnerships comes from the RDS surveys of MSM in Port Moresby described above which recorded condom use with non-paying female partners, female clients, and FSW [6]. This survey was carried out in 2005 and the condom use values were relatively high, between 47% and 67% at last act [6].

As discussed previously this highly sexually active population is not representative of the MSMW population in the model which is more similar to the general male population. Due to this we assume that condom usage between MSMW and general females and FSW is the same as the values for general males.

Sexual partner numbers for each population group and partnership formation

In the PNG HIV model the average number of sexual partners per year in each population group have with individuals in other population groups is used to calculate the force of infection. For PNG there is a rich anthropological and qualitative literature describing the sexual behaviour in the country which is of limited use for calibrating the model (e.g. [69-71]). To estimate the number of sexual partners specific population groups have each year, data was obtained from behavioural surveys of volunteers who were asked the number of sexual partners they had over a certain time period. The most useful measure for modelling purposes is the average or median number of partners in the previous year but in these surveys sexual partner numbers are usually categorized into casual, transactional, commercial (sex work), or regular (long term) partnerships and the numbers are often binned (e.g. 0 partners, 1 partner, > 2 partners). While these measures are not ideal they are useful for indicating the level of sexual activity and providing bounds for partner number estimates. In particular the proportion of the population that is married gives an indication of the number of regular partners individuals have each year. In terms of regular partnerships the number had each year includes long term partnerships (such as spouses) that are carried over from year to year.

For all female population groups a proportion of partnerships will be with MSMW with the remainder with general males. It is assumed that the proportion of partnerships with MSMW is equal to the proportion of the male population that is MSMW as shown in Table 4.

To match the differences in peak age of diagnosis for males and females and an expected split in the age of peak incidence a 5 year age difference in partner ages for females of all ages was used. Too large an age gap means the incidence in younger men is too low and testing rates for young men have to be unrealistically high to match the diagnoses data. Using the same age gap for casual and regular partnerships in all female population groups in the PNG HIV model results in females of a particular age group having partnerships mostly with men in the age group above theirs and ~10% of their partners will be with men 10-15 years older.

The PNG HIV model also allows the number of sexual partnerships to change with disease stage. While there is no data available describing changes in partner numbers for people diagnosed with HIV, suffering from AIDS, or on ART we assume a 5% reduction in partner numbers for individuals who have been diagnosed with primary or chronic HIV infection and a 15% reduction for individuals with late stage HIV/AIDS, on ART, or with virological failure. This assumption is based on the idea that people diagnosed with HIV change their sexual behaviour due to education or counselling post diagnosis, when they get treatment, or because of illness/sickness due to late stage disease or AIDS.

FSW and client partnerships

Female sex workers in urban and rural areas have casual and regular partnerships with general males and MSMW. For FSWs casual partnerships combine commercial clients and non-paying partners. For modelling purposes we assume all casual partnerships have the same characteristics and are representative of commercial partnerships. Regular partnerships between FSW and males consist of all long term partnerships that FSW have; e.g., husbands. We assume for the PNG HIV model that FSWs in each age group have more regular partners than general females but with the same age distribution. While commercial partnerships are assumed to be casual partners, FSWs may also have long term clients who repeatedly engage in sexual intercourse. For modelling purposes these long term partners are considered to be multiple casual partnerships which mean the casual partner numbers may be increased to incorporate long term client partnerships. Nevertheless some partnerships with long term clients may be more like marital partnerships and such partnerships are counted in FSWs regular partnerships. As for general females a proportion of casual and regular partnerships are specified to be with general males with the remainder of the partnerships with MSMW. We assume this proportion is the same as for general females.

In this section the number of casual/commercial partners FSWs in each age group have with males is estimated and used to calculate the number of casual partners they have with each male age group. Within the model the total number of partnerships males have with FSWs is then calculated using the distributions and partnership balancing described previously.

A number of surveys and studies of FSWs have been carried out in PNG providing data on partner numbers [4, 6, 26, 35, 42, 68, 72]. Generally, self defined commercial sex workers report 150-300 sex partners in the previous year [26]. One study of transport and sex workers began in 1996 and assessed the impact of an education and peer support program for HIV prevention. In this study ongoing changes in FSW sexual behaviour were measured within the program participants but the initial estimates for partner numbers are likely to be representative of background sexual behaviour. The number of clients per week for FSWs in Port Moresby was measured to be 2.9 (150 per year) in 1996 and 4.9 (255 per year) in 1998 while for Lae the number of partners per week was 3.2 (166 per year) in 1996 and 2.6 (135.2) in 1998. Similarly, in a survey of 407 self-identified FSWs conducted during 1998-99 the number of clients per week in Port Moresby and Lae was reported to be 3.5 (182 per year) and 3.0 (156 per year), respectively, with an overall mean of 3.3 (172 per year) clients per week [68]. A more recent survey of 211 FSWs along the Highlands Highway in 2001-02 found that the number of clients per week ranged between 1 and 8 with a mean of 3 clients per week (156 per year) [42].

Data from other surveys from the last decade remain consistent with the results from earlier surveys. A respondent driven survey of 235 FSWs in Port Moresby 227 FSWs in Goroka during 2005 reported that over 70% had between 1 and 6 clients in the previous week (50-300 per year) [6]. For Port Moresby 21.1% had more than 7 partners in the previous week while the corresponding value for Lae was 9.2%. For this survey the mean or median number of partners per week was not reported, rather partner numbers where binned into 0, 1-3, 4-6, 7-9, and >= 10 clients per week. If we assume that FSWs with >= 10 clients per week have on average 12 clients per week and multiply the reported proportions with the midpoint value of these ranges then the average number of clients per week in Port Moresby and Lae is equal to 4.6 (239.2 per year) and 3.6 (187.2 per year), respectively. Finally a behavioural surveillance survey of highway and non-highway based FSWs in Lae and Mt Hagan in 2006 recorded the number of clients and non-paying partners FSWs had in the previous week [4]. Highway based FSWs had a median of 2 clients per week (104 per year) compared to 4 clients per week (208 per year) for non-highway based FSWs. As for the previously discussed survey the partner numbers where binned into 0, 1-3, 4-6, 7-10, and >= 11 partners per week. Performing the same weighted average calculation under the same assumptions results in highway based FSWs having an average of 3.2 clients and 2.1 non-paying partners in the previous week. For non-highway based FSWs these averages are 4.8 and 1.3, respectively. Based on this survey we estimate that overall highway and non-highway FSWs have 5.3 (275.6 per year) and 6.1 (317.2 per year) casual partners per week. In a 2010 survey of 441 FSW in Port Moresby the average number of clients per week was 6.2 (322.4 per year) [5]. All of the values obtained and estimated for the number of casual partners FSWs are shown in Figure 11.

As there is no data available describing the number of clients or commercial partners versus the age of FSWs we assume that FSWs have the same casual partner number distribution with age as general females. The actual number of casual partners FSWs have per year is calibrated in the model to both match the available data and reproduce the trends seen in the overall HIV prevalence in PNG and the estimated HIV prevalence within FSWs. These values are given in Table 4 with the value for the 30-34 age group plotted in Figure 11. The data in Figure 11 shows that the number of partners FSW have each year is highly uncertain but appears to be relatively level over time. As there is limited data comparing urban and rural FSW populations we assume that FSW in urban and rural populations have the same number of partners each year.

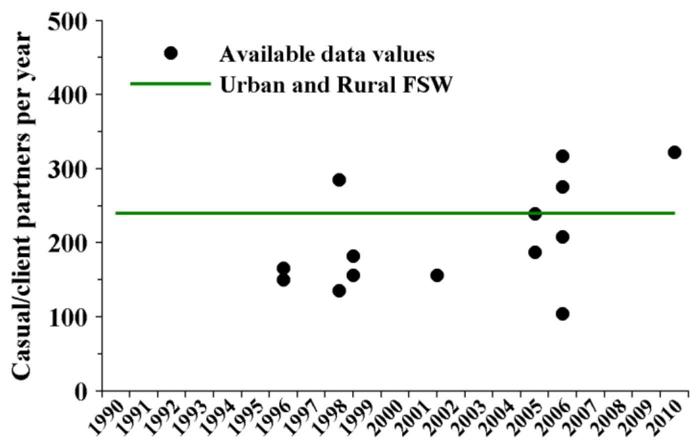


Figure 11: Number of casual partners per year for FSWs from 1990 to 2010. The black discs correspond to actual data values or estimates based on available data while green line represents the annual partner numbers for 30-34 year old age FSW in the PNG HIV model.

MSMW partnerships

As discussed previously there is a great deal of uncertainty in the size of the MSMW population in PNG and their sexual behaviour. In terms of the number of sexual partners only one respondent driven sampling survey has reported the type and number of partners MSMW have each year [6, 29]. This study was conducted in Port Moresby and surveyed 227 men in 2005 older than 16 who have had sex with another man in the 12 months prior to being interviewed [6]. This survey population had a very high level of sexual activity. In the month prior to being interviewed: 66.7% having more than 1 non-paying male partner; 29.9% had more than 1 one-time male client; 44.1% had more than one regular client; 47.8% had more than 1 non-paying female partner; 4.9% had more than 1 female client; and 19.2% had more than one FSW partner. These results are similar to those found in a 2010 survey of 96 men who sell sex in Port Moresby [5]. In this survey the men had on average 2.9 clients per week (150.8 per year) with 50% having more than 1 casual non-paying partner and 54% having more than 1 non-paying regular partners in the previous six months. In terms of sexual behaviour 69% had vaginal intercourse, 57% had anal intercourse with females, and 71% had anal intercourse with the same sex in the previous six months [5].

This diversity and number of sexual partnerships implies this population of men is at high risk of acquiring HIV and it is highly unlikely that the majority of MSMW in the PNG population have this level of sexual behaviour given that the estimated HIV prevalence in MSMW is 4.3% [13] and 0.37% of HIV transmissions are reported to be due to homosexual contact, where the mode of transmission has been recorded [14].

Due to the low number of recorded transmissions from homosexual contact and the relatively low HIV prevalence in MSMW we assume the average number of male partners MSMW have each year is low, at 2 casual partners and 0.1 regular partners per year for urban MSMW, reflecting infrequent sexual intercourse between men on average. These values are calibrated to the available HIV epidemiology data in PNG (shown in Table 4) and are assumed to be the same for all age groups. Finally we assume urban MSMW have double the sexual partners of rural MSMW to reflect the presence of a higher sexually active homosexual population in urban areas.

Partnerships between General Females and Males

In this section the number of partners general females in each age group have with males is estimated. These estimates are then used to calculate the number of partners with each male age group, and the number of partnerships a male has with females on average, using the distributions and partnership balancing described in the methods section. A proportion of these partnerships are specified to be with general males with the remainder of the partnerships with MSMW. While we need to estimate the number of partners females have each year, partnership balancing allows the use of male partnership data to estimate the female partner numbers (assuming an approximate 1:1 sex ratio).

Estimates for the number of sexual partners for the general population were obtained from a small number of reports describing the results from behavioural surveys [4, 10, 13, 26, 27, 64, 65, 73]. Most of these studies bin the number of partners into broad categories (for example 0, 1, or > 1 partners per year) making it difficult to estimate the number of partners per year. One study described in a book published in 1995 on sexual behaviour in PNG provided the lifetime and yearly number of sexual partners from 95 sexually active men and 91 sexually active women [25]. On average the men had 3.7 partners in the previous year with 37.7% of these men having one partner and 57.3% having two or more partners. The number of partners in the previous year for each male age group was also reported with a wide range of partner numbers varying between 1.9 partners and 7.4 partners (due to the small numbers for each age). There tended to be higher values for 25 to 40 year olds but overall there was a gradual decline in numbers from slightly more than 4 for 15 year olds to approximately 3 for 60 year olds. Additionally the lifetime number of partners for men varied greatly with age ranging between 1 and 100 partners but the age trend consisted of a gradual increase from approximately 10 partners at 15 years to about 20 partners by 60 years. For the surveyed women the average number of partners was 3.5 in the previous year with 49.4% having one partner and 45.6% having two or more partners.

Another survey of Eastern Highlands youths conducted in 1998 [26] reported similar but higher numbers of sexual partners with males (both married and single) having a median number of 5 partners in the preceding year, single women having a median of 4.5 partners, and married women having 2 partners. In this study a high percentage of the population had more than 10 partners in the previous year ranging between 11% (for married females) and 29% (for married men).

These results from these two studies from the 1990s suggest that there is a relatively high level of sexual activity in the general PNG population which gradually declines with age. This has been reinforced with more recent studies, such as a study at the Port Moresby General Hospital STI Clinic in 2005 which recorded that almost all the participants had more than 1 partner in the previous 3 months with 15% having more than 5 partners [73].

In more recent reports the mean number of partners per year is usually not documented rather partner numbers are stratified into crude categories. One behavioural survey of males and females reported that 48% to 62.3% of the population had one partner in the previous year and

8.9% to 38.7% of the population had more than one partner in the previous 12 months with married females having the least number of partners [4]. Similarly, in a recent biological and behavioural survey of males and females in urban and rural areas across PNG 44% to 55.9% of urban males (for married and single males respectively) had more than one partner in the previous 12 months; this compares with approximately 40% of males in rural areas having more than one partner. There was a similar difference in the proportions for urban and rural females however the proportion of females with more than one partner tended to be less than that for males particularly for married females [4]. These wide ranging but similar proportions for the number of people with more than one partner in the previous year are consistent to that reported for various population groups in the 2008 and 2010 PNG UNGASS reports [13, 27] and the data from the 1995 survey described above [25] where 57.3% of males and 45.6% of females had two or more partners in the previous 12 months. This relative consistency suggests that the number of sexual partners per year in the general population has been consistent over time from 1990 to 2010. However, given the increased prevalence, awareness, and fear of HIV in PNG we might expect partner numbers to decrease in the general population. The consistency seen could be due to surveys recruiting individuals voluntarily meaning they represent individuals that consider themselves to at risk of infection due to their sexual behaviour.

The biological and behavioural survey discussed above also measured the number of regular partnerships males and females had in the previous year depending on their marital status 21% to 29% of urban men had more than one regular partner in the previous year compared to a range of 5% to 29% for urban women. For rural males and females the corresponding ranges were slightly lower at 13% to 22% and 4% to 32% respectively. This suggests that general females have between 1 and 2 regular partnerships each year. There is little other data available specifying the number of regular partnerships, however, the marital status of individuals is often recorded which can provide a lower bound for the number of regular partners. From population surveys the proportion of males and females married tends to be greater than 60% [4, 10] with a substantial proportion of married men having two or more wives [10]. For youths the data can be conflicting with the some surveys giving the proportion of 15-24 year olds married to be 10% to 20% [4] while other studies give the average age of marriage to be 16 to years of age (which is soon after sexual debut) [27]. This married data suggests that on average individuals in the general population have at least 0.6 regular partners each year.

The available data discussed here suggests that during the 1990s females had between 3 and 5 sexual partners annually (combining casual and regular partners). The exact values used for casual and regular partner numbers in the PNG model is shown in Table 4 and are calibrated to match the available HIV epidemiological data for PNG while being representative of the behavioural data presented in this section. As there is limited data comparing urban and rural populations we assume that females in urban and rural populations have the same number of partners each year. In terms of the variation in the number of casual partners with age the limited data available suggests that younger people have more casual partners with a decline over time. To model this decline we assume a linear decrease with age in casual partner numbers for general females as shown in Table 4. For regular partners we assume the change in the number of partnerships with age has a peak in the 20-24 and 25-29 year age groups similar to the change in the birth rate with age shown in Table 2. The change in birth rate with age is likely to be representative of the relative change in the proportion of females who are married or with long term sexual partners. All general females 35 and older are assumed to have the same number of regular partners reflecting their likely marital status.

If all the sexual behaviour parameters other than condom use remain fixed over time then the PNG HIV model accurately reflects the initial growth in the estimated prevalence and incidence of HIV within PNG from 1990 to 2000 (see Figure in the PNG HIV Model – Summary and Results Report) but the levelling off in prevalence and the peak and fall in incidence is not captured by the model unless there is a change in HIV transmission parameters over time from around the year 2000. To achieve a flattening out in HIV prevalence the number of partners between general females and general males is reduced over the 2000 to 2010 period by 10%. While there is limited data to suggest such changes in these sexual behaviour values these reductions are reasonable. Since the year 2000 there has been an expansion of education and knowledge campaigns and VCT services increasing the awareness of HIV which is likely to create more concern surrounding HIV and result in changes in behaviour such as reductions in sexual partners. Under this assumption the model produces a simulated incidence curve that levels off and falls slightly after 2003. The fall in incidence after 2003 is not as large as the EPP projection estimates from the NDOH [2]. The model can follow the estimated incidence curve more closely but this requires a much larger reductions in the number of sexual partners after 2000 that are likely to be unrealistic.

Table 4: Sexual behaviour parameters for urban and rural populations in PNG
Parameter values used to describe the sexual behaviour of specific populations groups in urban and rural PNG from 1990 to 2010. The value of each of these parameters can vary over time from 1990 to 2010.This is shown by specifying the parameter value for 1990, 2000, and 2010 and displaying the change graphically in the main text where appropriate. Footnotes provide more details and the references for the parameter values with further details in the main text.

<table>
<tr><th>Description</th><th>Estimated Values</th><th>Interface</th><th>Footnote</th></tr>
<tr><td colspan="4">Sexual Partners – Urban General Females</td></tr>
<tr><td>Number of casual and regular partners per year with urban males</td><td>
<table>
<tr><td rowspan="2">Age Group</td><td colspan="3">Number of Casual Partners</td><td colspan="3">Number of Regular Partners</td></tr>
<tr><td>1990</td><td>2000</td><td>2010</td><td>1990</td><td>2000</td><td>2010</td></tr>
<tr><td>0-4</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>5-9</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>10-14</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>15-19</td><td>6</td><td>6</td><td>4.2</td><td>0.7</td><td>0.7</td><td>0.49</td></tr>
<tr><td>20-24</td><td>5.3</td><td>5.3</td><td>3.7</td><td>1.1</td><td>1.1</td><td>0.78</td></tr>
<tr><td>25-29</td><td>4.7</td><td>4.9</td><td>3.3</td><td>0.8</td><td>0.8</td><td>0.59</td></tr>
<tr><td>30-34</td><td>4</td><td>4</td><td>3</td><td>0.7</td><td>0.7</td><td>0.525</td></tr>
<tr><td>35-39</td><td>3.3</td><td>3.3</td><td>2.3</td><td>0.6</td><td>0.6</td><td>0.42</td></tr>
<tr><td>40-44</td><td>2.7</td><td>2.7</td><td>1.8</td><td>0.6</td><td>0.6</td><td>0.42</td></tr>
<tr><td>45-49</td><td>2</td><td>2</td><td>1.4</td><td>0.6</td><td>0.6</td><td>0.42</td></tr>
<tr><td>50-54</td><td>1.3</td><td>1.3</td><td>0.92</td><td>0.6</td><td>0.6</td><td>0.42</td></tr>
<tr><td>55-59</td><td>0.7</td><td>0.7</td><td>0.48</td><td>0.6</td><td>0.6</td><td>0.42</td></tr>
<tr><td>> 60</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>
</td><td>Yes</td><td>b1</td></tr>
<tr><td>Proportion of casual and regular partners with urban general males</td><td colspan="2">Equal to 1 minus the proportion of men that are MSMW</td><td>b2</td></tr>
<tr><td colspan="4">Sexual Partners – Urban FSW</td></tr>
<tr><td>Number of casual and regular partners per year with urban males</td><td>
<table>
<tr><td>Age</td><td>Number Casual</td><td>Number Regular</td></tr>
</table>
</td><td>Yes</td><td>b3</td></tr>
</table>

Group	Partners	Partners
0-4	0	0
5-9	0	0
10-14	0	0
15-19	360	1
20-24	319	1.6
25-29	281	1.2
30-34	240	1
35-39	199	0.85
40-44	161	0.85
45-49	120	0.85
50-54	79	0.85
55-59	41	0.85
> 60	0	0

Proportion of casual and regular partners with urban general males	Equal to 1 minus the proportion of men that are MSMW	b4
Sexual Partners – Urban General Males		
Number of casual and regular partners with urban females	Balanced with general female and FSW partner numbers	b5
Sexual Partners – Urban MSMW		

<table>
<tr><td>Number of casual and regular partners with MSMW per year</td><td>
<table>
<tr><th>Age Group</th><th>Number Casual Partners</th><th>Number Regular Partners</th></tr>
<tr><td>0-4</td><td>0</td><td>0</td></tr>
<tr><td>5-9</td><td>0</td><td>0</td></tr>
<tr><td>10-14</td><td>0</td><td>0</td></tr>
<tr><td>15-19</td><td>2</td><td>0.1</td></tr>
<tr><td>20-24</td><td>2</td><td>0.1</td></tr>
<tr><td>25-29</td><td>2</td><td>0.1</td></tr>
<tr><td>30-34</td><td>2</td><td>0.1</td></tr>
<tr><td>35-39</td><td>2</td><td>0.1</td></tr>
<tr><td>40-44</td><td>2</td><td>0.1</td></tr>
<tr><td>45-49</td><td>2</td><td>0.1</td></tr>
<tr><td>50-54</td><td>2</td><td>0.1</td></tr>
<tr><td>55-59</td><td>2</td><td>0.1</td></tr>
<tr><td>> 60</td><td>0</td><td>0</td></tr>
</table>
</td><td>Yes</td><td>b6</td></tr>
<tr><td>Number of casual and regular partners with urban females</td><td colspan="2">Balanced with general female and FSW partner numbers</td><td>b7</td></tr>
<tr><td colspan="4">Sexual Partners – Rural General Females</td></tr>
<tr><td>Number of casual and regular partners with rural males per year</td><td>Same values as that for urban general females</td><td>Yes</td><td>b8</td></tr>
<tr><td>Proportion of casual and regular partners with rural general males</td><td colspan="2">Equal to 1 minus the proportion of men that are MSMW</td><td>b9</td></tr>
<tr><td colspan="4">Sexual Partners –Rural FSW</td></tr>
<tr><td>Number of casual and regular partners with rural males per year</td><td>Same values as that for urban FSW</td><td>Yes</td><td>b10</td></tr>
<tr><td>Proportion of casual and regular partners with rural</td><td colspan="2">Equal to 1 minus the proportion of men that are MSMW</td><td>b11</td></tr>
</table>

<table>
<tr><td>general males</td><td colspan="2"></td><td></td></tr>
<tr><td colspan="4">Sexual Partners –Rural General Males</td></tr>
<tr><td>Number of casual and regular partners with rural females per year</td><td colspan="2">Balanced with general female and FSW partner numbers</td><td>b12</td></tr>
<tr><td colspan="4">Sexual Partners –Rural MSMW</td></tr>
<tr><td>Number of casual and regular partners with MSMW per year</td><td>
<table>
<tr><th>Age Group</th><th>Number Casual Partners</th><th>Number Regular Partners</th></tr>
<tr><td>0-4</td><td>0</td><td>0</td></tr>
<tr><td>5-9</td><td>0</td><td>0</td></tr>
<tr><td>10-14</td><td>0</td><td>0</td></tr>
<tr><td>15-19</td><td>1</td><td>0.075</td></tr>
<tr><td>20-24</td><td>1</td><td>0.75</td></tr>
<tr><td>25-29</td><td>1</td><td>0.075</td></tr>
<tr><td>30-34</td><td>1</td><td>0.075</td></tr>
<tr><td>35-39</td><td>1</td><td>0.075</td></tr>
<tr><td>40-44</td><td>1</td><td>0.075</td></tr>
<tr><td>45-49</td><td>1</td><td>0.075</td></tr>
<tr><td>50-54</td><td>1</td><td>0.075</td></tr>
<tr><td>55-59</td><td>1</td><td>0.075</td></tr>
<tr><td>> 60</td><td>0</td><td>0</td></tr>
</table>
</td><td>Yes</td><td>b13</td></tr>
<tr><td>Number of casual and regular partners with general females and FSW per year</td><td colspan="2">Balanced with general female and FSW partner numbers</td><td>b14</td></tr>
<tr><td colspan="4">Change in partner numbers due to HIV infection</td></tr>
</table>

Percentage reduction in the number of sexual partners for HIV infected individuals due to their HIV infection	(see table below)	Yes	b15

	Casual Partners	Regular Partners
Undiagnosed Primary	0%	0%
Undiagnosed Chronic	0%	0%
Undiagnosed AIDS	15%	15%
Diagnosed Primary	5%	5%
Diagnosed Chronic	5%	5%
Diagnosed AIDS	15%	15%
First line ART	15%	15%
First line ART Failure	15%	15%
Second line ART	15%	15%
Second line ART Failure	15%	15%

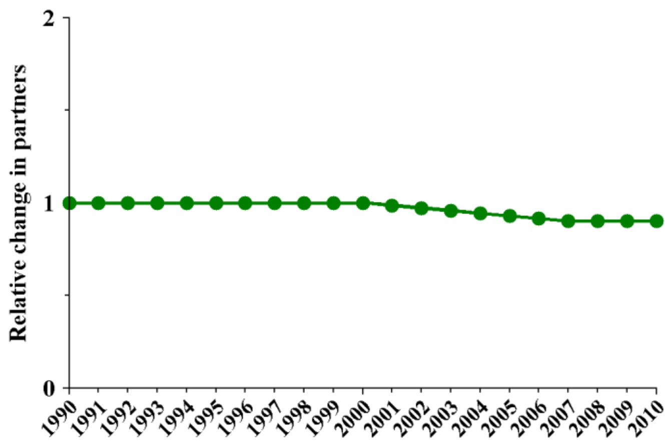
Condom Usage

Per act probability of condom usage	(see table below)	Yes	b16

Partnership type	Casual partnerships			Regular partnerships		
	1990	2000	2010	1999	2000	2010
urban general female-general male	5%	22.5%	40%	2.5%	8.75%	15%
urban general female-MSMW	5%	22.5%	40%	2.5%	8.75%	15%
urban FSW-general male	10%	45%	70%	5%	22.5%	40%
urban FSW-MSMW	10%	45%	70%	5%	22.5%	40%
urban MSMW-MSMW	10%	25%	40%	2.5%	8.75%	15%
rural general female-general male	2.5%	11.3%	20%	1.3%	4.38%	7.5%
rural general female-MSMW	2.5%	11.3%	20%	1.3%	4.38%	7.5%
rural FSW-general male	5%	22.5%	35%	2.5%	11.3%	17.5%
rural FSW-MSMW	5%	22.5%	35%	2.5%	11.3%	17.5%
rural MSMW-MSMW	5%	12.5%	20%	1.3%	4.38%	7.5%

General parameters

Acts of sexual intercourse	1	No	b17

per casual partnership			
Acts of sexual intercourse per regular partnership	100		
b1 to b14: The parameters describing the number of sexual partners each population group has each year are described in detail in the main text. The values here have been calibrated to the HIV epidemic in PNG from 1990 to 2010 and change over time. We assume all populations groups have the same relative reduction in partners which is shown in the figure below and results in a 10% reduction from the 1990 value by 2010:  b15: A small reduction in partner numbers is assumed for individuals with AIDS or who have been diagnosed with HIV due to illness and education/counselling. b16: The probability of a condom being used in particular partnerships is described in detail in the main text. b17: These values are assumptions calibrated to the HIV epidemiological data for PNG and are common in mathematical HIV modelling. For regular partnerships the 100 acts corresponds to the assumed number of acts in a long term regular partnership each year.			

Baseline HIV Clinical Parameters

The parameters and assumptions used to describe clinical characteristics of the HIV epidemic in PNG are described in this section. Such parameters include the rate of testing for HIV in each population group, the average time taken for someone with late stage HIV or AIDS to be clinically diagnosed, and the rate that people begin ART and experience treatment failure. The final default parameter values are listed in Table 5.

The PNG HIV model incorporates the uptake of second line ART therapy and treatment failure. However, second line therapy is only just becoming available in PNG so we assume there is currently no second line therapy in the model up until the end of 2010. The uptake, adherence/drop-out, and failure rates for second line therapy can be easily incorporated into the model for evaluating the future direction of the HIV epidemic and the impact of interventions in PNG through the software interface.

Unfortunately there is little data on common behavioural trends related to HIV testing and ART usage with no national surveillance reports describing trends or population characteristics [16]. National reports tend to simply state the number of HIV tests carried out each year and the number of people who have started ART [3, 14]. This means, while all clinical parameters in the model can vary with age, there is not enough information to describe and model all the clinical characteristics of different age groups. For modelling purposes we therefore assume that each population and age group within urban and rural areas has the same level of ART initiation and the same rate of treatment failure.

For parameters describing testing there is cumulative diagnoses data for each male and female age group for the 1987 to 2008 period. This is used to calibrate the default testing rates in the PNG HIV model as described below. Also there are a number of studies among particular population groups allow differences in clinical characteristics to be ascertained [3, 4, 13, 14, 16].

Testing rates and AIDS diagnosis

A HIV infected person can be diagnosed with HIV via a blood test or clinically if they have symptoms of late stage HIV or AIDS. The number of HIV tests conducted overall in PNG has increased from 1407 in 2004 to 120607 in 2008. This rapid increase in testing corresponds with a rapid scale up in the number of testing sites right across PNG from only 4 sites in 2004 to 201 sites in 2008 [14]. This rapid scale up of testing was initiated with the establishment of sentinel surveillance in 2002 [3] with an expansion of testing in antenatal clinics, STI clinics, the screening of blood donors, and tuberculosis patients as well as in VCT sites across the country [3].

While testing for HIV did occur throughout the 1990's it mainly occurred in urban areas particularly at the Port Moresby general hospital which was the only place offering VCT in the early 1990s [3]. It is likely that the majority of people travelled to Port Moresby and other urban centres to get tested for HIV after they started to experience symptoms of their infection. This means that prior to 2002 the majority of HIV diagnoses are likely to be due to a clinical diagnosis in an urban centre with a small proportion of the population being tested prior to the development of symptoms. Such a pattern in diagnoses gives an explanation for why in some years the number of people diagnosed with HIV is greater than the number of tests carried out. For example in 2004 there were 1407 HIV tests carried out but 2636 HIV diagnoses recorded [14].

In terms of specific population groups a number of surveys have reported whether individuals have ever been tested previously [4-6, 16]. Often these results do not give the frequency of testing within a population and have only been conducted recently but they do give an indication of the level of testing within a population. A 2006 survey of adult male workers in occupations considered to be at high risk of HIV infection reported that between 7.7% and 26.4% of males had a voluntary HIV test previously in their lives and obtained their results [4, 16]. Male military personal were also surveyed and 74.5% were found to have had a HIV test, however, this is not surprising as HIV testing is a requirement of entry into the armed forces [4]. Another study in 2006 recorded the proportion of out of school youth (aged between 15 and 24 years) in Port Moresby who have previously been tested for HIV [4]. The results showed that between 7.1% and 17.9% of the population had been tested with the highest proportion in married females [4]. These survey results are likely to be indicative of HIV testing in the general population in recent years. In surveys of FSWs the frequency of testing is often recorded. For example one survey during 2005 found that 17.5% of FSWs in Port Moresby and 9.8% of FSWs in Goroka had underwent VCT in the last year [6]. A follow up study found higher levels of testing with 34 to 35% of FSWs reporting they went to a VCT centre in Port Moresby and Goroka in the past 12 months [16]. A survey conducted in 2006 reported that 48.4% of non-highway FSWs and 42.1% of highway FSWs had previously tested for HIV [4]. For MSMW the only testing data available is from the RDS of highly sexually active MSM in Port Moresby, discussed previously, with 24% of men undergoing VCT in the previous year [6]. Finally, a more recent study of FSWs in Port

Moresby conducted in 2010 showed a wide disparity in testing with 51% of surveyed FSWs having received a HIV test in the last 12 months while 39% had never been tested for HIV.

This data is useful for informing the level of testing within particular populations within PNG but is not detailed enough to use directly in the calibration of the PNG HIV model. This means a large number of assumptions are required to calibrate the PNG HIV model to available diagnoses data. The first assumption we make is that testing rates and the rate of AIDS diagnoses for rural population groups is 25% less than the rates for rural population groups reflecting the lack of access to medical services for people in rural areas. We assume that the same proportion of general males and MSMW in each age group is tested each year. People with AIDS are assumed to be diagnosed at a much higher rate than those in the primary and chronic stages due to the presence of symptoms and the ability to be diagnosed clinically. The clinically/symptomatic based diagnosis of AIDS is also assumed to be independent of age and population group.

As services for testing individuals for HIV have expanded substantially in recent years with the, wide scale roll-out of VCT services and ANC testing, we assume all population and age groups have the same relative increase in testing rates over time and match the annual diagnoses obtained from the model with the annual diagnoses reported for PNG.

The annual number of diagnoses recorded by the PNG HIV model also depends on the initial level of testing in 1990. To calibrate the testing rates in 1990 urban FSW age groups have a testing rate set to 0.2, which is much higher than the testing rate for general females, and all urban MSMW have a testing rate set to 0.1, which is higher than the testing rates for general males. The testing rates for general males and females are allowed to vary with age and are set so that the cumulative number of diagnoses in each male and female age group from 1990 to 2008 matches the diagnoses data in PNG (see Figure 5 and Figure 3 in the PNG HIV Model – Summary and Results report). Note that age has not been recorded for 44% of the reported diagnoses in PNG so for calibration purposes we multiply the number of diagnoses obtained by the model in each age group by 0.56 to compare the model results with the data in Figure 5.

To match the age distribution in male diagnoses the same testing rate for all male age groups is used (see Table 5). For general females a much higher testing rate is required for younger females than older females with a peak in the age groups with the highest birth rate. These differences between males and females are reflected in available testing data with 120,607 HIV tests conducted in 201 testing site throughout PNG in 2008 [14]. Of these tests 71% were conducted in females, however, if ANC tests are excluded then only slightly more tests were conducted in females than males for that year (39,034 versus 35,320 respectively)[14]. Therefore, the higher levels of testing in younger female age groups in the PNG HIV Model reflect ANC testing.

Using the testing rates in Table 5 with the other baseline parameter values the PNG HIV model produces diagnoses results which closely match the available diagnoses data (see Figure 5 and Figure 3 in the PNG HIV Model – Summary and Results report). This is particularly true for the number of annual diagnoses but the age distribution for cumulative diagnoses is very similar to the data presented in Figure 5 with females having a peak diagnosis in the 20-24 year age group and males have a peak diagnosis in the 30-34 year age group with more male diagnoses than female diagnoses in older age groups. The overall proportion of diagnoses that are female is around 60% which is representative of available data in recent years (but potentially unrealistic in earlier years when there was less ANC testing) [14].

The model accurately represents the diagnoses data for PNG overall but the testing rates required are high compared to the proportion of the population that get tested each year in PNG. For urban FSWs the testing rates rise from 10% in 1990 to 40% in 2010 which seem reasonable given the available survey data presented above. However, for younger general males the testing rate increases to 20% and for urban general females in the 20 to 24 year old age group the rate increases to 40% per year by 2010. The testing rates required for the general population perhaps suggest that the HIV epidemic is concentrated within particular populations or geographic regions which have previously been targeted successfully with HIV testing.

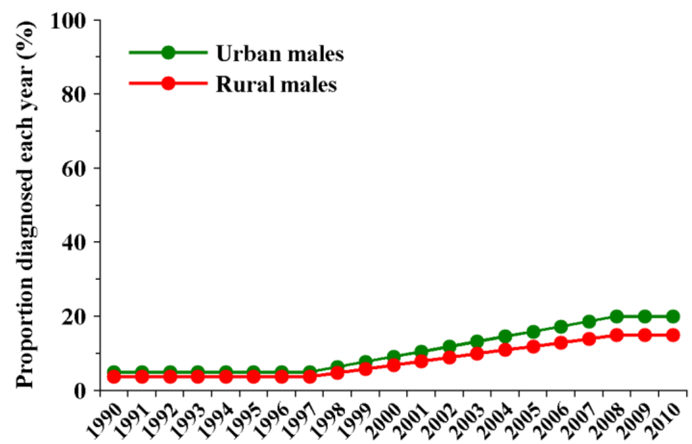
Anti-retroviral therapy

First line antiretroviral therapy has only been available in PNG since the end of 2003. Besides records of the number of people who have started ART there is limited data on the roll out of ART and the characteristics of people receiving it. HIV infected individuals in PNG begin taking ART following the WHO guidelines [74]. This means we assume that only people in the AIDS stage of infection receive ART in the PNG HIV Model. However, earlier initiation of treatment can be implemented as an intervention strategy. This means the rate that infected individuals with AIDS is likely to be the same for all population and age groups.

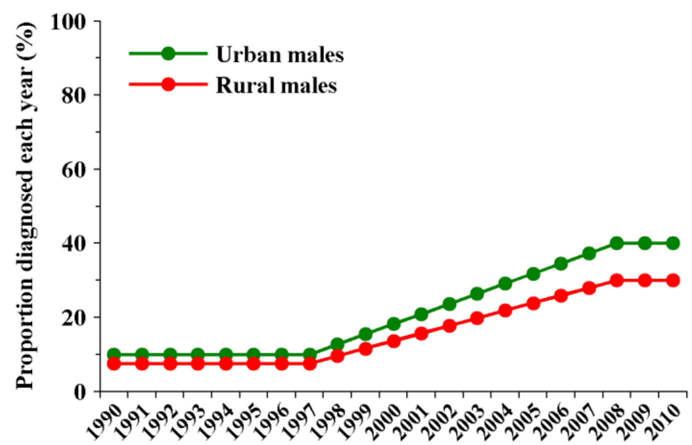
The rapid expansion of ART services means that the number of people that have begun ART in PNG has increased rapidly from 2004. This data is used to set the rate that people with late HIV infection or AIDS begin treatment in the PNG HIV model. The rate of ART initiation used in the model results in a simulated ART coverage that is representative of estimates provided by the NDoH [2] with a rapid increase after 2004.

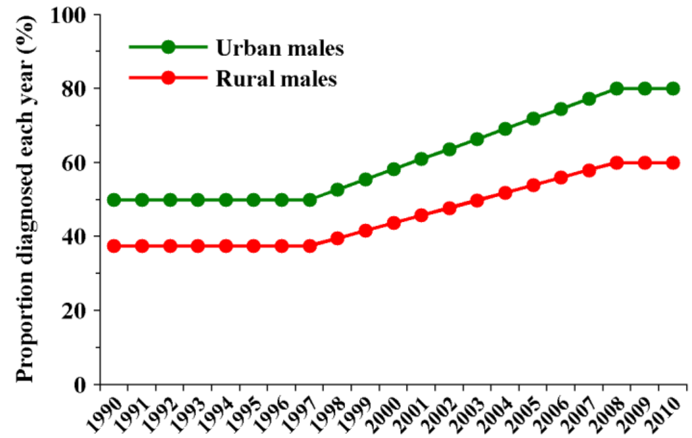
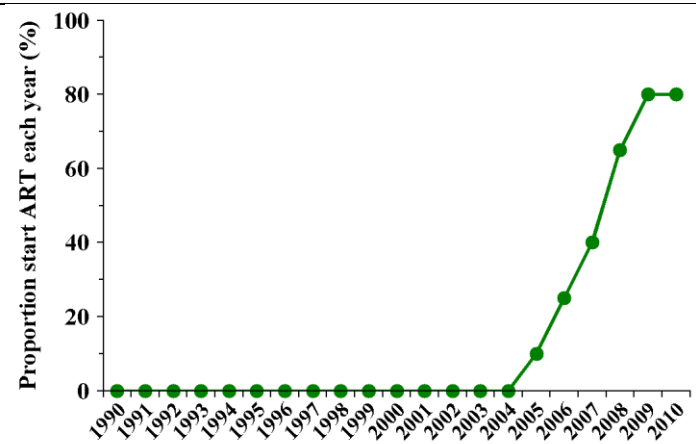
Table 5: Parameter Table for default clinical parameters

Parameter values used to describe the clinical characteristics of population groups in urban and rural PNG from 1990 to 2010. These parameters are used to simulate the testing, diagnosis, ART initiation, and ART failure in the PNG population overall. The value of each of these parameters can vary over time from 1990 to 2010. Footnotes provide more details and the references for the parameter values with further details in the main text. The interface column specifies whether the values can be changed in the PNG HIV Model interface.

Description	Estimated Values	Interface	Footnote
Diagnoses rates			
Proportion of general males and MSMW with primary or chronic HIV infection that are diagnosed with HIV each year		Yes	d1
Proportion of general females with primary or chronic HIV infection that are diagnosed with HIV each year	(see table below)	Yes	d2

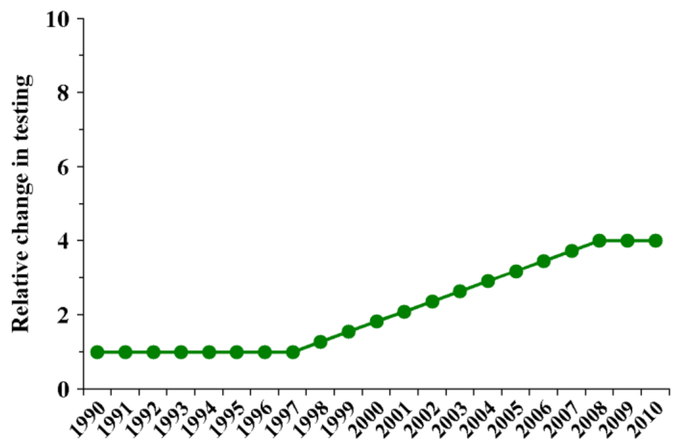
Age Group	Urban General Females			Rural General Females		
	1990	2000	2010	1990	2000	2010
0-4	0	0	0	0	0	0
5-9	0	0	0	0	0	0
10-14	0	0	0	0	0	0

<table>
<tr><td></td><td>
<table>
<tr><td>15-19</td><td>0.08</td><td>0.15</td><td>0.32</td><td>0.06</td><td>0.11</td><td>0.24</td></tr>
<tr><td>20-24</td><td>0.1</td><td>0.18</td><td>0.4</td><td>0.08</td><td>0.14</td><td>0.3</td></tr>
<tr><td>25-29</td><td>0.05</td><td>0.09</td><td>0.2</td><td>0.038</td><td>0.068</td><td>0.15</td></tr>
<tr><td>30-34</td><td>0.04</td><td>0.072</td><td>0.16</td><td>0.03</td><td>0.055</td><td>0.12</td></tr>
<tr><td>35-39</td><td>0.04</td><td>0.072</td><td>0.16</td><td>0.03</td><td>0.055</td><td>0.12</td></tr>
<tr><td>40-44</td><td>0.04</td><td>0.072</td><td>0.16</td><td>0.03</td><td>0.055</td><td>0.12</td></tr>
<tr><td>45-49</td><td>0.04</td><td>0.072</td><td>0.16</td><td>0.03</td><td>0.055</td><td>0.12</td></tr>
<tr><td>50-54</td><td>0.04</td><td>0.072</td><td>0.16</td><td>0.03</td><td>0.055</td><td>0.12</td></tr>
<tr><td>55-59</td><td>0.04</td><td>0.072</td><td>0.16</td><td>0.03</td><td>0.055</td><td>0.12</td></tr>
<tr><td>> 60</td><td>0.04</td><td>0.072</td><td>0.16</td><td>0.03</td><td>0.055</td><td>0.12</td></tr>
</table>
</td><td></td><td></td></tr>
<tr><td>Proportion of FSWs with primary or chronic HIV infection that are diagnosed with HIV each year</td><td>
</td><td>Yes</td><td>d3</td></tr>
</table>

AIDS Diagnosis			
Proportion of people with AIDS that are diagnosed each year.		Yes	d4
Anti-retroviral Treatment (ART) Parameters			
Proportion of HIV infected individuals with diagnosed AIDS that begin first line ART treatment each year.		Yes	d5
Proportion of people on first line ART in urban areas that experience	10%	Yes	d6

treatment failure each year			
Proportion of people on first line ART in rural areas that experience treatment failure each year	20%		
Second Line ART		Yes	d7

d1 – d3: The testing rates for each population age group are discussed in detail in the main text. It is assumed that rural testing rates are 25% less than those for urban populations due to lower access to medical services. The relative change in testing rate from 1990 to 2010 is assumed to be the same for each population and age group. No variation with age in testing rates is assumed for general males, MSMW, or FSW populations. Younger general females have higher testing rates than older females due to ANC testing and are calibrated to match the cumulative number of diagnoses in each age group [1]. All populations are assumed to have the same relative increase in testing over time from 1998 to 2007 (assumed to be linear) to match the rise in recorded diagnoses in PNG [1]. This relative rise is shown below:



General males and MSMW are assumed to have the same testing rates overall while FSW are assumed to have a higher testing rate than general females due to their higher risk of acquiring HIV and to reflect available testing data.

d4: Individuals with AIDS have a higher testing rate due to the presence of clinical symptoms. Since diagnosis more likely to be based on clinical symptoms we assume it is the same for each population group except that urban populations have a higher rate than rural populations due to better access to medical services. Diagnoses rates for people with AIDS are assumed to be much higher than for the rates during primary and chronic HIV infection and are calibrated so that simulated annual diagnoses matches the recorded diagnoses in PNG overall [1].

d5: ART treatment only became available in PNG at the end of 2003, since then HIV infected individuals have been given treatment based on the WHO guidelines [74]. Available evidence from the 2008 STI, HIV, and AIDS Annual Surveillance Report [14] shows that ART has been rapidly rolled out and the latest estimates of ART coverage from the NDoH show that by 2010 up to 80% of people requiring treatment are receiving it [2, 14]. As ART initiation is based on the WHO guidelines we assume that diagnosed HIV infected individuals with late HIV or AIDS in all population groups are given ART at the same rate. This rate of ART initiation is calibrated to match the reported number of people who have started ART for PNG [2, 14]. By 2010 the rate of ART initiation corresponds to an average period of 6 months between being diagnosed with late HIV or AIDS and beginning ART treatment. It might be expected that due to logistical issues and lack of access to ART services the rate that the population in rural areas begins treatment would be lower than that urban areas but due to the high estimates for ART coverage in PNG [2] we assume the same rate of ART initiation for both urban and rural areas (with the differences between urban and rural areas contained in the AIDS diagnoses rate).

d6: There is no data available on HIV treatment failure in PNG. Due to this lack of data we simply assume that all population and age have the same failure rate with urban areas having half the failure rate of rural areas reflecting lower access to ART services. The rates we use are based on available clinical data [75]. We assume rural populations have a higher failure or equivalently shorter duration until failure due to the difficulty of accessing treatment regularly which is likely to result in lower adherence.

d7: The model allows second line ART therapy to be described. However, up until 2010 there was limited 2nd line ART available in PNG so it hasn't been included in the default parameter table. The rate that people start 2nd line ART and the 2nd line failure rate are available in the interface.

Discussion: Issues with Calibration and Model Limitations

Using the parameter values in Tables Table **2**-Table **5** the PNG HIV model produces a simulated HIV epidemic that satisfies the assumptions listed at the end of the HIV epidemiology in PNG from 1990 to 2010 section and is a good representation of the HIV epidemic in PNG (as shown in Figures 2 and 3 in the PNG HIV Model – Summary and Results report). Calibrating these parameters to satisfy these assumptions and match available data was difficult and required a large number of assumptions to be made due to the complexity of the model and a lack of data for many parameters. These assumptions and the default parameters used need to be considered when interpreting the results.

In particular the following aspects of model parameterisation are particularly important because they have a large impact on the simulated HIV epidemiological trends:

- The proportion of the population in urban and rural areas that are MSMW and FSWs. There is very little data on the actual number of women who engage in sex work and the length of time they engage in this activity but this can have a large impact on the simulated prevalence of HIV within the adult population. Similarly there is very little data on the overall number of men who have sex with men on a regular basis and variations in the proportion of males that are MSMW can have a large effect on simulated outcomes.
- The proportion of males circumcised and with penile cutting and the efficacy of penile cutting in preventing HIV acquisition. There is only a small amount of data on the proportion of men in PNG who have undergone some form of penile cutting. This data rarely separates the penile slitting from circumcision (complete removal of the foreskin) and the protective effect of penile cutting completely unknown (meaning we had to simply assume a 20% efficacy in the model). The results produced by the PNG HIV model are sensitive to these parameters and more accurate data would improve the results obtained from the model.
- For the model to produce a simulated epidemic representative of the overall HIV epidemic in PNG the per-act reference transmission probability from males to females had to be relatively large compared to results from meta-analyses (see Table 3). As explained in the section on HIV biology and transmission parameters this larger value could reflect the level of heterosexual anal sex and sexual violence in PNG. However, there is limited data describing the frequency and proportion of acts involving heterosexual anal intercourse to verify a higher value.

- To achieve a levelling off in adult HIV prevalence after 2010 the model requires a change in sexual behaviour to reduce the risk of HIV transmission. This was achieved in the model by reducing the number of partners general females have each year by 10% (from 2000 to 2010). There is little data to suggest that such a reduction has occurred in PNG though it is not unreasonable to expect such a change given the roll-out of programmes to increase the level of knowledge over the last decade and the likely exposure to friends or family that have become HIV-positive.
- In the model the testing/diagnosis rates of young females need to be high by 2010 to match available diagnoses data. This rate is likely to be much higher than what is occurring in reality in PNG. The high rates of diagnosis required in the model potentially reflect that the individuals most at-risk of HIV infection are the ones being tested for HIV currently in PNG. If this is the case then the epidemic in PNG could be much more concentrated than what has been assumed in the model

The assumptions required to calibrate the model potentially highlight limitations with the model or the assumptions about the HIV epidemiology in PNG used for calibration. In particular the model assumes a relatively homogenous HIV epidemic but potentially there is much more heterogeneity with individuals in particular regions, settings, or population groups being at a much higher risk of HIV infection. Future research that fills in these gaps would lead to improved forecasts from the PNG HIV Model and would be useful for the development of other models of HIV transmission in PNG.

References

1. The 2009 STI, HIV and AIDS Annual Surveillance Report. (2010) National Department of Health STI, HIV and AIDS Surveillance Unit: Port Moresby, Papua New Guinea.
2. Kitur, I., PNG HIV Epidemic Update. (2009) Presented at the 2009 Australasian Society for HIV Medicine Conference: Brisbane, Australia.
3. The 2007 Estimation Report on the HIV Epidemic in Papua New Guinea. (2008) National AIDS Council: Port Moresby, Papua New Guinea.
4. *Millan, J., et al.,HIV/AIDS Behavioural Surveillance Survey Within High Risk Settings. (2006) National AIDS Council Sectetariat and National HIV/AIDS Support Project: Port Moresby, Papua New Guinea.*
5. Kelly, A., et al., Askim na save (ask and understand): People who sell and exchange sex in Port Moresby. Key Qunatitative Findings. (2011) Papua New Guinea Institute of Medical Research and the University of New South Wales: Sydney, Austrlia.
6. Maibani-michie, G., et al. (2005) Baseline Research for Poro Sapot Project, in Prevention. Final Pre-Intervention Research Report. Papua New Guinea Institute of Medical Research: Goroka, Papua New Guinea.
7. Millan, J. Sexual Behaviour in Adult Male Workers in Papua New Guinea. (2009) Presented at the 2009 Australasian Society for HIV Medicine Conference: Brisbane, Australia.
8. Anderson, R.M. and R.M. May, Age-dependent choice of sexual partners and the transmission dynamics of HIV in Sub-Saharan Africa. Philosophical Transactions of the Royal Society London B, 1992;336:135-155.
9. Hoare, A., et. al., Sampling and sensitivity analyses tools (SaSAT) for computational modelling. Theoretical biology & medical modelling, 2008;5:4.
10. Gray, R.T., et al., A Behavioural and Biological Survey of HIV and STIs in Papua New Guinea 2003-2008 - Draft Report. (2010) Papua New Guinea Institute of Medical Research: Goroka, Papua New Guinea.
11. Vallely, A., et al., The prevalence of sexually transmitted infections in papua new Guinea: a systematic review and meta-analysis. PloS one, 2010;5:e15586.
12. Ghys, P.D., et al., The UNAIDS Estimation and Projection Package: a software package to estimate and project national HIV epidemics. Sexually Transmitted Infections, 2004;80 Suppl 1:i5-9.
13. UNGASS 2010 Country Progress Report Papua New Guinea. (2010) Papua New Guinea National AIDS Council Secretariat and Partners: Port Moresby, Papua New Guinea.
14. The 2008 STI, HIV and AIDS Annual Surveillance Report. (2009) National Department of Health STI, HIV and AIDS Surveillance Unit: Port Moresby, Papua New Guinea.
15. Gregson, S., et al., Sexual mixing patterns and sex-differentials in teenage exposure to HIV infection in rural Zimbabwe. The Lancet, 2002;359:1896-1903.
16. King, E. and Lupiwa, T. A Systematic Literature Review of HIV and AIDS in Papua New Guinea 2007-2008. (2009) Port Moresby, Papua New Guinea.

17. The World Bank Data Catalog (accessed 4/05/2010; available at http://data.worldbank.org/country/papua-new-guinea).
18. Papua New Guinea 2000 Census National Report. (2003) Papua New Guinea National Statistical Office: Port Moresby, Papua New Guinea.
19. Demographic and Health Survey. (2009) National Statistical Ofice: Port Moresby, Papua New Guinea.
20. U.S. Census Bureau International Programs website (accessed 03/09/10; available at: http://www.census.gov/population/international/data/idb/informationGateway.php)
21. Life Tables for WHO Member States - Papua New Guinea 2006 (accessed 17/03/2009 from *www.who.int/whosis/database/life_tables/life_tables_process.cfm)*
22. Papua New Guinea: Epidemiological Fact Sheets on HIV/AIDS and Sexually Transmitted Infections. (2006) UNAIDS: Geneva Switzerland.
23. Papua New Guinea Summary Country Profile for HIV/AIDS Treatment Scale-up. (2005) World Health Organization: Geneva Switzerland.
24. Knauft, B.M., What ever happened to ritualized homosexuality? Modern sexual subjects in Melanesia and elsewhere. Annual Review of Sex Research, 2003;14:137-159.
25. National Study of Sexual and Reproductive Knowledge and Behaviour in Papua New Guinea. (1994) The Nationa Sex and Reproduction Research Team and Carol Jenkins, Papua New Guinea Institute of Medical Research: Goroka, Papua New Guinea.
26. Jenkins, C., HIV/AIDS, Culture, and Sexuality in Papua New Guinea in Cultures and Contexts Matter: Understanding and Preventing HIV in the Pacific. (2007) Asian Development Bank: Manila, Philippines.
27. UNGASS 2008 Country Progress Report Papua New Guinea. (2008) Papua New Guinea National AIDS Council Secretariat and Partners: Port Moresby, Papua New Guinea.
28. 2007 Oceania AIDS Epidemic Update Regional Summary. (2008) UNAIDS andWHO: Geneva, Switzerland.
29. Yeka, W., et al., Application of respondent driven sampling to collect baseline data on FSWs and MSM for HIV risk reduction interventions in two urban centres in Papua New Guinea. Journal of Urban Health: Bulletin of the New York Academy of Medicine, 2006; 83:i60-72.
30. Auvert, B., et al., Randomized, controlled intervention trial of male circumcision for reduction of HIV infection risk: the ANRS 1265 Trial. PLoS medicine, 2005;2:e298.
31. Bailey, R.C., et al., Male circumcision for HIV prevention in young men in Kisumu, Kenya: a randomised controlled trial. The Lancet, 2007;369:643-656.
32. Gray, R.H., et al., Male circumcision for HIV prevention in men in Rakai, Uganda: a randomised trial. The Lancet, 2007;369: p. 657-666.
33. Weiss, H.A., et al., Male circumcision for HIV prevention: from evidence to action? AIDS, 2008;22:567-574.

34. Hill, P.S., et al., A typology of penile cutting in Papua New Guinea: results of a modified Delphi study among sexual health specialists. AIDS Care, 2011:1-10,iFirst.
35. Jenkins, C., The Transex Project: Sex and Transport Workers, Police and Security Men in Papua New Guinea in Female Sex Worker HIV Prevention Projects (pg: 19-56). (2000) UNAIDS: Geneva, Switzerland .
36. Quinn, T., et al., Viral load and heterosexual transmission of human immunodeficiency virus type 1. NEJM, 2000;342:921-929.
37. Wilson, D., et al., Relation between HIV viral load and infectiousness: a model-based analysis. The Lancet, 2008;372:314-22.
38. Attia, S., et al., Sexual transmission of HIV according to viral load and antiretroviral therapy: systematic review and meta-analysis. AIDS, 2009;23:1397-404.
39. Boily, M.-C., et al., Heterosexual risk of HIV-1 infection per sexual act: systematic review and meta-analysis of observational studies. Lancet Infectious Diseases, 2009;9:118.
40. Jin, F., et al., Per-contact probability of HIV transmission in homosexual men in Sydney in the era of HAART. AIDS, 2010;24:907-13.
41. Ryan, C.E., et al., The heterosexual HIV type 1 epidemic in Papua New Guinea is dominated by subtype C. AIDS research and human retroviruses, 2007;23:941-4.
42. Gare, J., et al., High prevalence of sexually transmitted infections among female sex workers in the eastern highlands province of Papua New Guinea: correlates and recommendations. Sexually Transmitted Infections, 2005;32:466-473.
43. Lewis, I., et al., *Final Report on Links Between Violence Against Women and the Transmission of HIV in 4 Provinces of PNG*. (2008)
44. Barnabas, R.V. and J.N. Wasserheit, Riddle of the Sphinx revisited: the role of STDs in HIV prevention. Sexually transmitted diseases, 2009;36:365-7.
45. Celum, C., et al., Acyclovir and Transmission of HIV-1 from Persons Infected with HIV-1 and HSV-2. NEJM, 2010:362;427-39.
46. Steen, R., et al., Control of sexually transmitted infections and prevention of HIV transmission: mending a fractured paradigm. Bulletin of the World Health Organization, 2009;87:858-865.
47. De Cock, K.M., et al., Prevention of mother-to-child HIV transmission in resource-poor countries: translating research into policy and practice. JAMA, 2000;283:1175-82.
48. Dunn, D.T., Risk of Human Immunodeficiency Virus Type-1 Transmission Through Breastfeeding. The Pediatric Infectious Disease Journal, 1993;12:264.
49. Kourtis, A.P., et al., Mother-to-child transmission of HIV-1: timing and implications for prevention. Lancet infectious diseases, 2006;6:726-32.
50. Nduati, R., et al., Effect of breastfeeding and formula feeding on transmission of HIV-1: a randomized clinical trial. JAMA, 2000;283:1167-74.
51. Zijenah, L.S., et al., Timing of mother-to-child transmission of HIV-1 and infant mortality in the first 6 months of life in Harare, Zimbabwe. AIDS, 2004;18:273.
52. Smith, D.M., The controversies of nevirapine for preventing mother-to-child HIV transmission. AIDS, 2006;20:281-3.

53. John-Stewart, G.C., et. al., Antiretroviral strategies to prevent mother-to-child transmission of HIV: striking a balance between efficacy, feasibility, and resistance. PLoS medicine, 2009;6:e1000169.
54. Vittinghoff, E., et al., Per-contact risk of human immunodeficiency virus transmission between male sexual partners. American Journal of Epidemiology, 1999;150:306-11.
55. Wawer, M.J., et al., Rates of HIV-1 Transmission per Coital Act, by Stage of HIV-1 Infection, in Rakai, Uganda. Journal of infectious diseases, 2005;191:1403-1409.
56. Davis, B.K.R. and S.C. Weller, The Effectiveness of of Condoms in Reducing HIV Transmission Heterosexual. Family Planning Perspectives, 1999;31:272-279.
57. Pinkerton, S.D. and P.R. Abramson, Effectiveness of condoms in preventing HIV transmission. Social science & medicine, 1997;44:1303-12.
58. Ledergerber, B., et al., Predictors of trend in CD4-positive T-cell count and mortality among HIV-1-infected individuals with virological failure to all three antiretroviral-drug classes. Lancet, 2004;364:51-62.
59. Smith, C., et al., Causes of death in the D:A:D study-initial results. 2008.
60. Todd, J., et al., Time from HIV seroconversion to death: a collaborative analysis of eight studies in six low and middle-income countries before highly active antiretroviral therapy. AIDS, 2007; 21 Suppl 6:S55-63.
61. Kilmarx, P.H., et al., Disease progression and survival with human immunodeficiency virus type 1 subtype E infection among female sex workers in Thailand. The Journal of infectious diseases, 2000; 181:1598-606.
62. Porter, K. and B. Zaba, The empirical evidence for the impact of HIV on adult mortality in the developing world : data from serological studies. AIDS, 2004;18: S9-S17.
63. Rangsin, R., et al., The natural history of HIV-1 infection in young Thai men after seroconversion. JAIDS, 2004;36:622-9.
64. Passey, M., et al., Screening for sexually transmitted diseases in rural women in Papua New Guinea: are WHO therapeutic algorithms appropriate for case detection? Bulletin of the World Health Organization, 1998;76:401-411.
65. Passey, M., et al., Community based study of sexually transmitted diseases in rural women in the highlands of Papua New Guinea: prevalence and risk factors. Sexually transmitted infections, 1998; 94:120-127.
66. Consensus Report on STI, HIV and AIDS Epidemiology (2000) National AIDS Council: Port Moresby, Papua New Guinea.
67. Bio-Behavioural Sentinel Surveillance Survey among Women attending Port Moresby General Hospital Antenatal (PPTCT) Clinic. (2008) Aruwafu, D.H. and F. Akuani, Behavioural Surveillance Survey Unit, Social and Environmental Studies Division, the National Research Institute: Port Moresby, Papua New Guinea.
68. Mgone, C.S., et al., Human immunodeficiency virus and other sexually transmitted infections among female sex workers in two major cities in Papua New Guinea. Sexually Transmitted Diseases, 2002;29:265-270.

69. Herdt, G., Madness and Sexuality in the New Guinea Highlands. Social Research, 1986;53:349-367.
70. Knauft, B.M., Text and Social Practice: Narrative "Longing" and Bisexuality among the Gebusi of New Guinea. ETHOS, 1986;14:252-281.
71. Knauft, B.M., Foucault Meets South New Guinea: Knowledge, Power, Sexuality. ETHOS, 1994;22:391-438.
72. Yeka, W., et al., Preliminary findings from a behvaioural survey of FSWs in Port Moresby and Goroka: a pre-intervention assessment for HIV. Presented at the 2005 PNG Medical Symposium.
73. 2004 National HIV/AIDS Consensus Workshop: Key Findings Summary and Analysis. (2005) PNG National AIDS Council: Port Moresby, Papua New Guinea.
74. Guidelines for the use of antiretrovial therapy in Papua New Guinea. (2003) National AIDS Council and National Department of Health: Port Moresby, Papua New Guinea.
75. Smith, C.J., et al., The rate of viral rebound after attainment of an HIV load <50 copies/mL according to specific antiretroviral drugs in use: results from a multicenter cohort study. Journal of Infectious Diseases, 2005;192:1387-97