CHAPTER 1

BACKGROUND AND BASIC CONCEPTS

It is obvious that the characteristics of a specific disease must be understood thoroughly in order to model that disease. Gonorrhea incidence, transmission, symptoms, complications and treatments are described in sections 1.1 and 1.2. Various current and potential control procedures for gonorrhea are described in section 1.3. Among the several basic types of models for infectious diseases described in section 1.4, it is apparent that one type is suitable for gonorrhea. A brief description of previous work on the mathematical modeling of gonorrhea is given. The concepts of the contact number and the infectee number are described in section 1.5.

1.1 The Magnitude of the Problem

As seen in figure 1.1, gonorrhea is the most frequently reported disease in the United States. Figure 1.2 shows that reported gonorrhea incidence in the United States tripled between 1965 and 1975. The increase of reported cases in this period is thought to represent an actual increase in gonorrhea incidence as well as improved procedures for case detection. Incidence is the number of new cases in a time interval such as a year, a month or a week. Reporting of gonorrhea, particularly by private health care providers, is incomplete in the United States so that reported incidence can only be used for determining trends or for comparing segments of the population.

Since 1975 the number of reported cases of gonorrhea has been about 1 million cases per year. Supplementary information such as extensive surveillance studies or polls of practicing physicians have been used to estimate that the **actual incidence of gonorrhea is now approximately two million cases per year in the United States.** The leveling off of reported cases after 1975 may be due to the gonorrhea control activities initiated in 1973 (CDC, 1981a).

Many countries have had rapid increases in the incidence of gonorrhea. The incidence of gonorrhea in several western countries including the United States, Canada, Denmark, Finland, Norway and United Kingdom was approximately level from 1955 to 1965 and generally increased from 1965 to 1975. Factors which may be responsible for the increased rates include: more frequent changes of sex partner, increased population mobility, increasing use of oral contraceptives, decreasing use of the condom and the diaphragm for contraception and

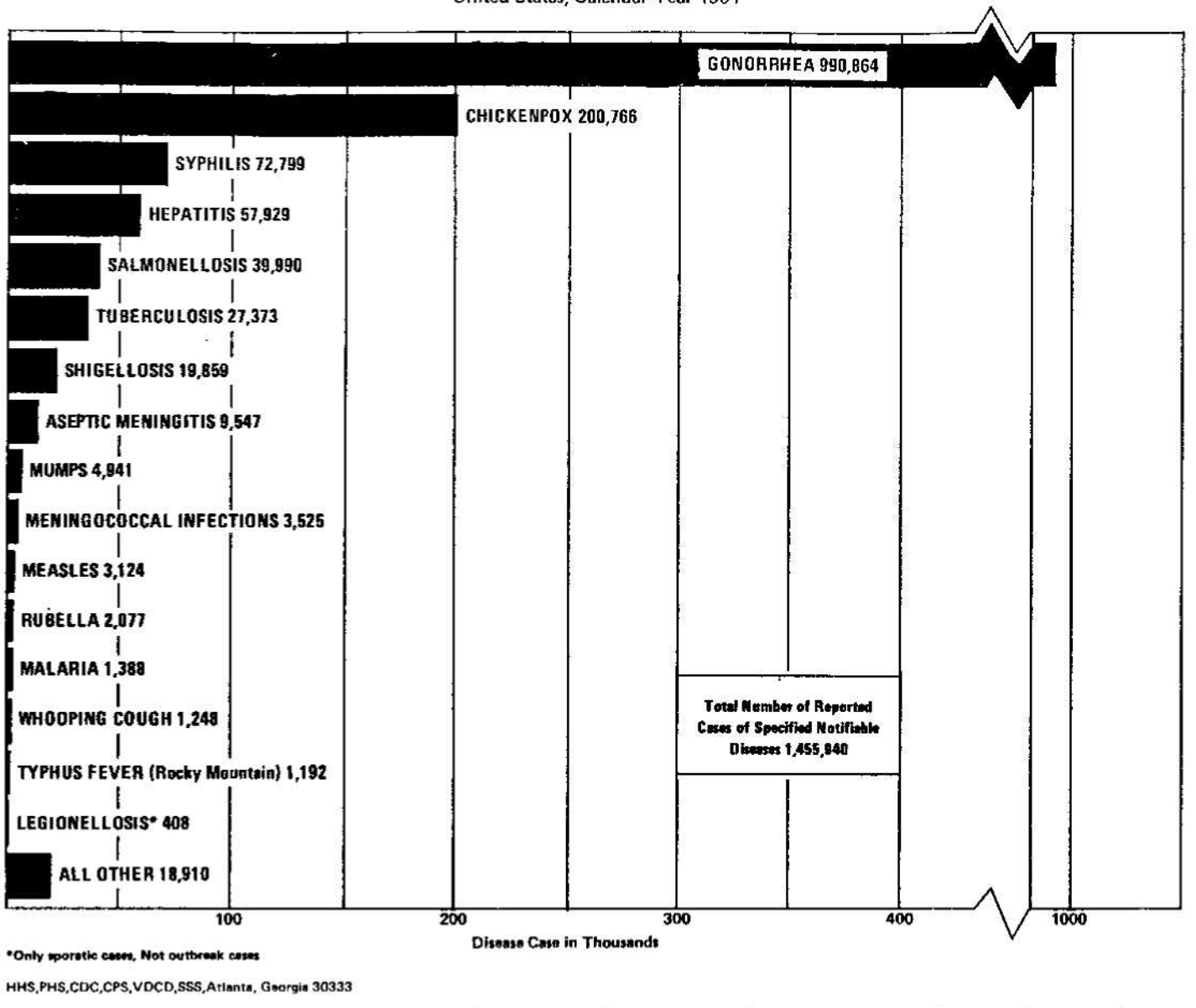


Figure 1.1. Reported cases of communicable diseases in the United States in 1981. Figure and permission from Statistical Services Section, Division of Venereal Disease Control, Centers for Disease Control.

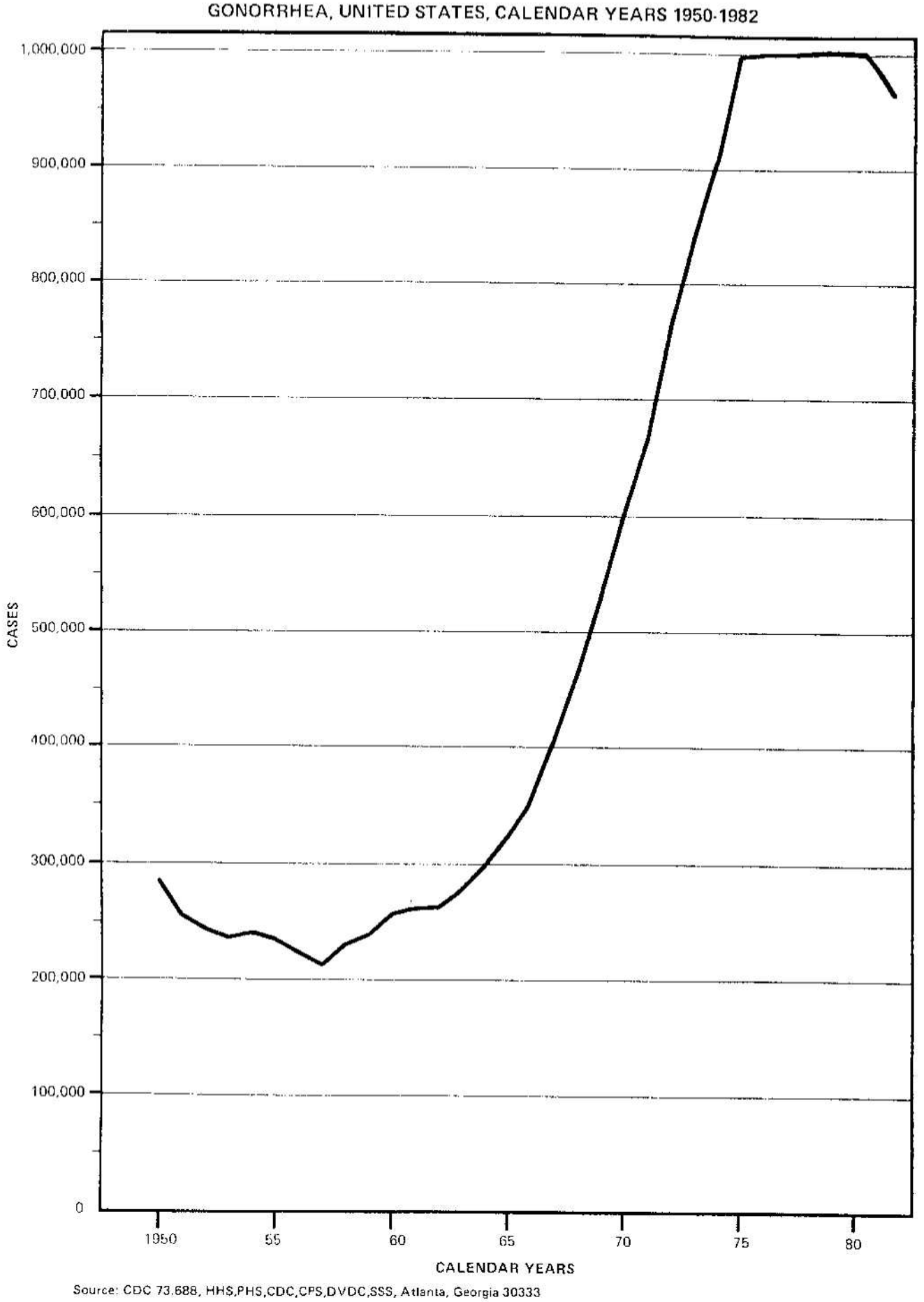
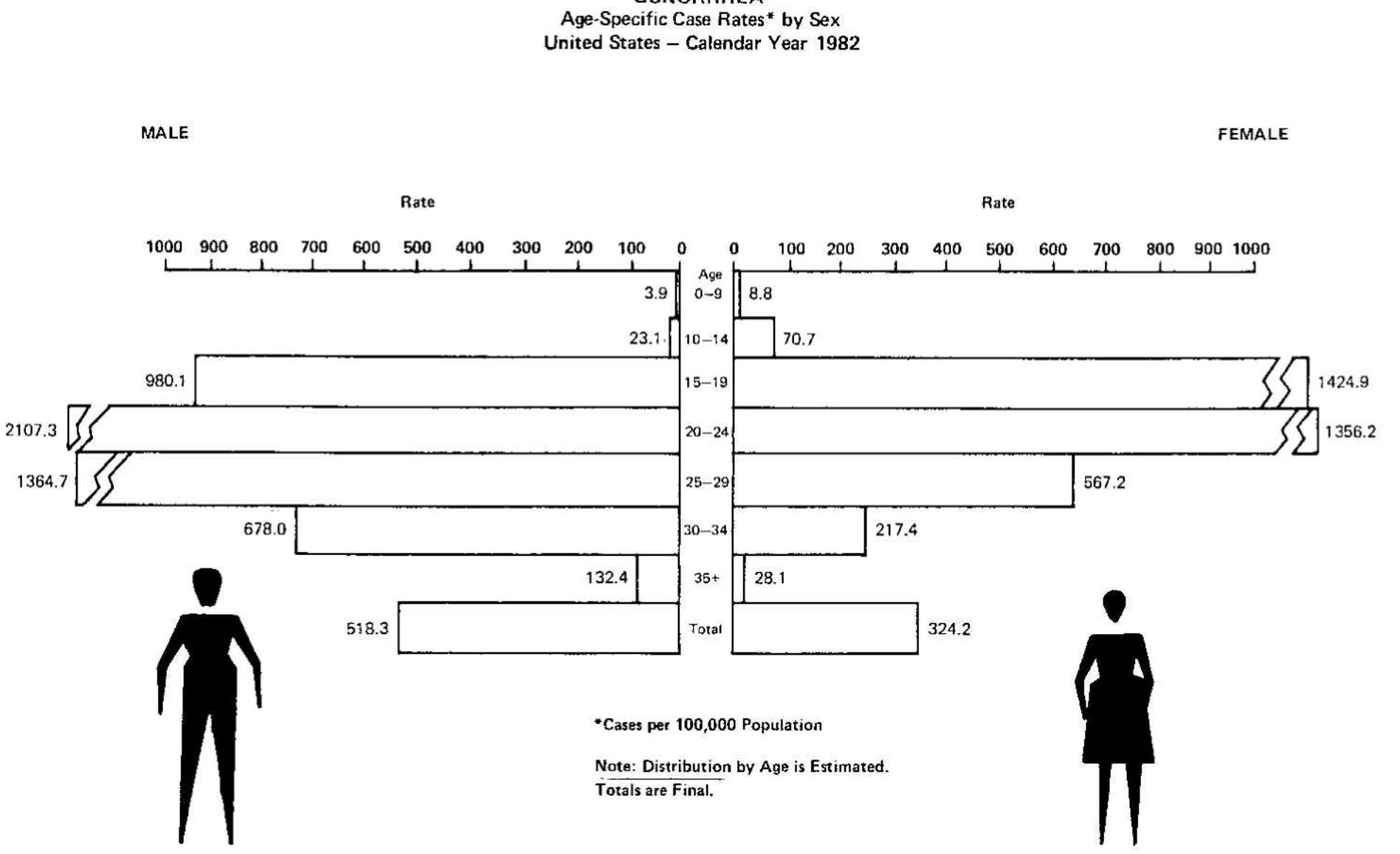


Figure 1.2. Reported cases of gonorrhea in the United States from 1950 to 1982. Figure and permission from Statistical Services Section, Division of Venereal Disease Control, Centers for Disease Control.



Source: CDC 9.2638. HHS, PHS, CDC, CPS, DVDC, SSS, Atlanta, Georgia 30333

Figure 1.3. Sex and age-specific case rates of gonorrhea in the United States in 1982. Figure and permission from Statistical Services Section, Division of Venereal Disease Control, Centers for Disease Control.

increasing gonococcal resistance to antibiotics (WHO, 1978). Reporting is relatively accurate in the United Kingdom where most cases are seen in clinics and in Denmark where most cultures are processed in a single laboratory. In the developing countries of Asia, Africa and Latin America, the reporting of gonorrhea is often very incomplete, but **annual incidences as high as 26% have been reported.** In those countries where extramarital sexual intercourse is common for men but not for women, a high proportion of men with gonorrhea are infected by prostitutes (WHO, 1978).

The demographic factors that correlate best with gonorrhea incidence are age, race, marital status, socioeconomic status and urban residence. Individuals who are single, have a lower socioeconomic status and reside in a large city are more likely to be infected by gonorrhea. As seen in figure 1.3 the age-specific incidence rates in the United States are highest for young adults (20 to 24 years of age) and second highest for teenagers (15 to 19 years of age). In 1978 young adults (ages 20-24) accounted for 39 percent and teenagers for 25 percent of reported gonorrhea cases. **Approximately one of 30 teenagers will acquire gonorrhea this year** (NIAID, 1980).

The great concern about the high incidence of gonorrhea results from the severe complications that some women suffer. Pelvic Inflamatory Disease (PID) is the most important complication. About 10 to 20 percent of women with gonococcal infection will suffer from PID. Data from the National Center for Health Statistics show that approximately **1 million women are treated for PID each year** including 212,000 who are hospitalized (about 50,000 required abdominal surgery). The direct hospitalization cost of PID in the United States has been estimated to be more than $600 million annually (Curran, 1980; NIAID, 1980). Infertility, ectopic pregnancy and chronic pelvic pain are important delayed consequences of gonococcal infection. In 1976 approximately 80,000 women were made sterile by gonococcal PID. The incidence of ectopic pregnancy rose from about 13,200 cases in 1967 to more than 41,000 cases in 1977 (NIAID, 1980; CDC, 1980b).

PID occurs when the fallopian tubes become swollen and inflamed due to infection. In many women who are unaware that they are infected with gonorrhea, the gonococci rise from the vagina and cervix into the uterus and then during menstruation spread up the sides of the uterus and into the fallopian tubes. When the inflamed fallopian tubes heal, the scarring may block the fallopian tubes causing involuntary infertility. Women with one episode of gonococcal PID have a 6% chance of becoming infertile and the likelihood of infertility

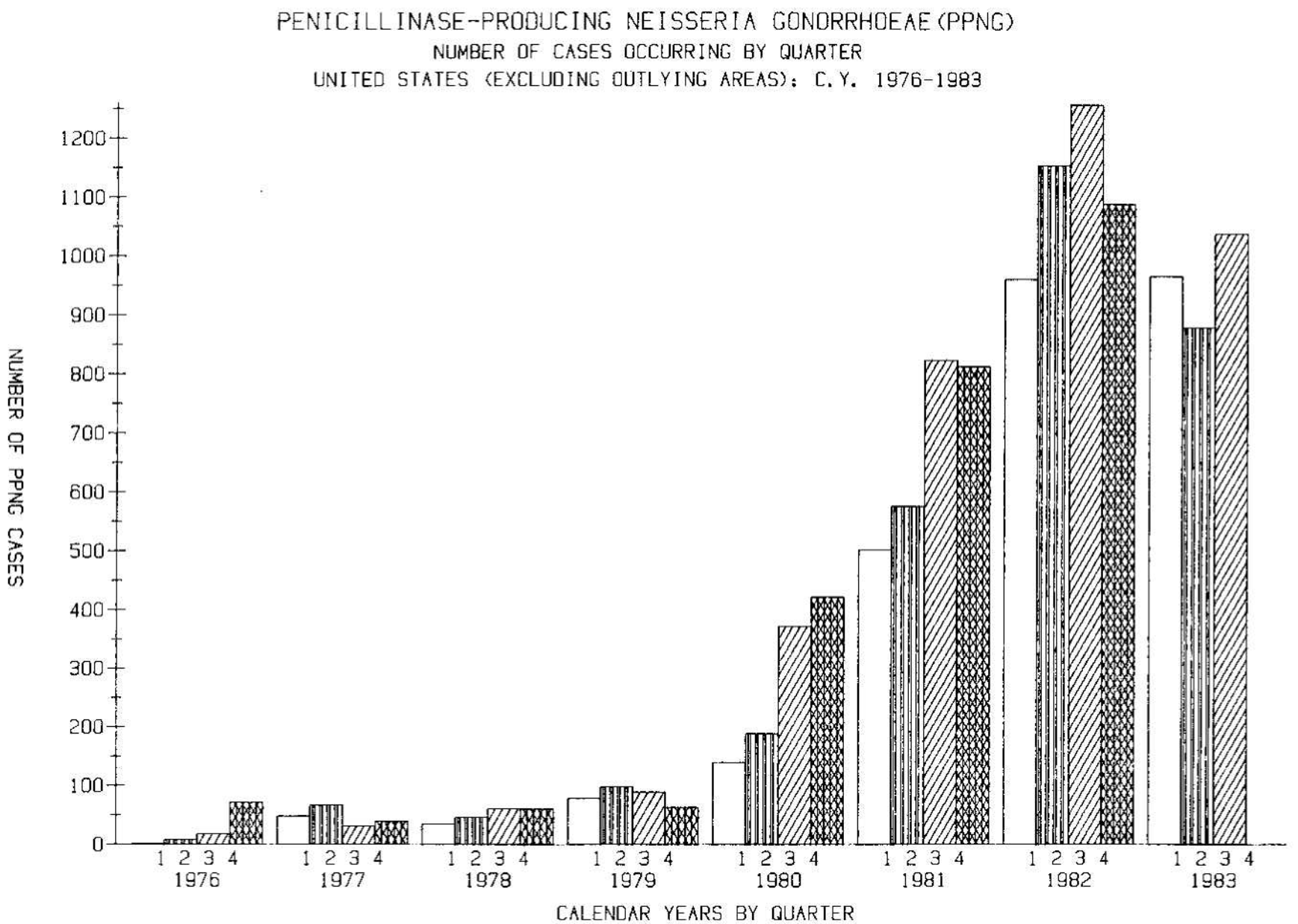


Figure 1.4. Reported cases of PPNG by quarter in the United States. Figure and permission from Statistical Services Section, Division of Venereal Disease Control, Centers for Disease Control.

increases with each subsequent episode. Since partial obstruction of the fallopian tubes can lead to ectopic pregnancy, women who have had PID are 6 to 10 times as likely to have an ectopic pregnancy as those who have not had PID. Adhesions on the ovaries, bowel or other tender pelvic structures that occur during the healing of acute PID cause chronic pelvic pain in 10% to 20% of patients (NIAID, 1980; Rein, 1977; WHO, 1978).

Some women are more likely to get PID than others. Women who use intrauterine devices (IUDs) are estimated to be about 3 times as likely to get PID from a gonococcal infection as those who use no contraceptive measures. Women who have multiple sex partners and women who have had PID before are more likely to get PID. Women who use oral contraceptives are less likely to get PID. Women who use barrier methods of contraception such as diaphragms, condoms, spermicidal foams, jellies or creams, are also somewhat protected against PID (WHO, 1978).

Penicillinase-producing Neisseria Gonorrhoeae (PPNG) consists of strains of gonococci which are resistant to all forms of penicillin. Penicillinase is an enzyme that destroys penicillin. **PPNG has now spread throughout the world** and 2 to 6 fold increases in PPNG have occurred in some countries in the last few years (CDC, 1982). Despite several early successful efforts in eliminating PPNG when it was introduced in the United States, it now appears to have become permanently established. Figure 1.4 shows that the number of reported cases of PPNG infection in the United States has increased every year since 1976. Not only are there more cases of PPNG infection imported from Southeast Asia, but also there is now sustained domestic transmission in major cities such as Los Angeles, New York City and Miami (CDC, 1982).

The standard treatment for gonococcal infection is the administration of penicillin. Because more expensive antibiotics are needed to cure PPNG, the treatment of gonorrhea could rapidly become more difficult and generally less effective so that incidence rates could increase. Efforts to control PPNG transmission in the United States include testing some gonococcal isolates for PPNG, rapid identification and tracing of sexual partners of PPNG patients, screening of groups who are at high risk of PPNG infection, and treatment of the following with spectinomycin: PPNG patients and their sexual partners, patients who were infected in countries with high PPNG prevalence, and patients for whom penicillin, ampicillin, amoxicillin or tetracycline was not effective treatment for gonorrhea (CDC, 1980).

In areas where more than 5% of gonococcal isolates are PPNG, it is recommended that the more expensive drug spectinomycin be used as the initial treatment for all cases (CDC, 1980a). Selection for drug resistant strains continues; recently, spectinomycin-resistant PPNG was found (CDC, 1981b).

1.2 The Infected Person

The gonococcus bacteria that causes gonorrhea grows well only on mucous membranes and dies in seconds outside the human body. The probability of transmission of gonococcal infection during a single sexual exposure from an infectious woman to a susceptible man is estimated to be from .2 to .3, while the probability of transmission from an infectious man is approximately .5 to .7 (Wiesner and Thompson, 1980). If sexual intercourse occurs with an infected partner several times, the probability of transmission of infection is increased. Taking these repetitions into account, it seems that in casual liasons an infectious man is roughly twice as likely to infect a susceptible woman as when the roles are reversed.

Gonococcal infection does not seem to confer immunity; more precisely, **none of the immunologic defense mechanisms has been shown to consistently prevent reinfections** (NIAID, 1980). This may be due to the great antigenic diversity of gonococcal surface antigens. In order for an individual to become infected, the gonococci must attach themselves to mucosal surfaces so that they will not be washed away by urine and mucosal flows. The gonococci have hair-like appendages called pili on their surfaces which facilitate their attachment. Local antibodies to Neisseria gonorrhoeae have been found on the mucosal surfaces which inhibit attachment of gonococci to epithelial cells; however, these antibodies disappear after the gonococcal infection ends. Humoral antibodies to N. gonorrhoeae have been demonstrated by a number of assays, but the presence of these antibodies has not been shown to correlate in any way with protection from reinfection. Lymphocyte activation and production of migration inhibition factor to various gonococcal antigens has been shown; however, the presence of a cellular immune response does not protect against reinfection. In individuals with Pelvic Inflamatory Disease the presence of bactericidal antibody does not protect individuals from either subsequent reinfection or PID. Although gonococcal infections usually remain localized on mucosal surfaces, some strains of gonococci can cause disseminated gonococcal infection. These strains seem to have a surface antigen which binds an IgG antibody

capable of blocking killing of the gonococci by normal human serum. Even disseminated gonococcal infection does not lead to humoral or cellular immunity that protects against reinfection (NIAID, 1980).

In men, the initial infection is in the anterior urethra so that some of the infecting organisms are removed with each urination Approximately 90 percent of all men who have a gonococcal infection notice symptoms within a few days after exposure and promptly seek medical treatment. Another 5 percent have mild or transient symptoms and the remaining 5 percent have totally asymptomatic infections. These latter two groups of men often fail to seek treatment and, consequently, are responsible for much of the transmission of disease to women. As many as half of the women with complications of gonorrhea were infected by asymptomatic men (NIAID, 1980). It has been estimated that approximately 5% of the incidence in men are asymptomatic and **asymptomatic men account for 60-80% of the prevalence** and hence 60-80% of the transmissions (Wiesner and Thompson, 1980). Complications of gonorrhea in men are rare today.

Studies of the course of the infection in women have been found to be dangerous since an infected woman is likely to develop PID during such a study. Consequently, investigations conducted before penicillin became available are often the most definitive studies available. One 1942 study analyzing prolonged untreated gonococcal infections among 73 inmates of the New York City House of Detention for Women is summarized below (Mahoney et al., 1942).

Most of the women were prostitutes. Each woman initially had a positive culture test for gonococci, and each was symptomatic. Each patient was cultured two or three times a week, when possible, for three to four months. Ten to twenty culture plates were used on each exam for each patient, instead of the customary two. Three patterns were observed. In each type the clinical symptoms usually remained without appreciable alteration throughout the observation period. No treatment was administered during the study; however, at least some patients were treated after the study before being released.

Type 1 (46% of the patients) remained positive. Usually each plate at an examination yielded approximately equal numbers of colonies.

Type 2 (42%) became and remained culture negative, though symptomatic.

Type 3 (12%) reverted to negative and after numerous consecutive negative findings had one or more positive findings sporadically appearing.

Due to the continued symptoms of all types, the investigators felt strongly that gonococcal infection remained despite the negative cultures. Menstrual periods had a negligible effect on the positivity or negativity of the examinations.

Although some reports indicated that the use of oral contraceptives affected the susceptibility of women, studies in venereal disease and family planning clinics show that the prevalence of gonococcal infections is not increased in women using oral contraceptives. However, hormonal factors do influence the clinical appearance of gonorrhea so that half of women with gonococcal PID seek medical attention in the first week of the menstrual cycle (WHO, 1978).

One recent estimate is that 50 to 75 percent of women with gonorrhea fail to have symptoms which cause them to seek medical care (NIAID, 1980). Another estimate is that 30-60% of the incidence in women is asymptomatic and that **asymptomatic women account for 80-90% of the prevalence** in women (Wiesner and Thompson, 1980). Asymptomatic women often remain untreated either until they develop PID or disseminated gonococcal infection or until they are examined and treated because they are suspected of transmitting infection or until they are discovered through mass screening by culture testing. Asymptomatic women and men form a vast reservoir of persons infected with gonorrhea. Transmission between homosexual men produces another reservoir of anorectal and/or pharyngeal infection (NIAID, 1980).

Precise diagnosis in both men and women depends on laboratory testing. The standard laboratory test for gonococci consists of bacteriological culturing of the patient's secretions. Serological tests are no longer used because of their low sensitivity and specificity (WHO, 1978). Except for PPNG, a single dose of penicillin is very effective in curing gonococcal infection. Other more expensive antibiotics are effective for PPNG.

1.3 Control Procedures

Gonorrhea control procedures are constantly being reevaluated in order to achieve the optimal use of available resources. One primary goal of this monograph is to compare gonorrhea prevention activities by means of mathematical models.

Educational programs either in clinics or in the media might make the sexually active population more aware of the symptoms and seriousness of gonorrhea so that people who suspect that they might be infected would seek examination and treatment sooner. Educational

programs can promote post exposure prophylaxis methods such as urination, local genital cleansing, douching and local antisepsis after intercourse. Individuals who use condoms are less likely to get gonorrhea. A national campaign in Sweden promoting condoms may have been a factor in the reduction of gonorrhea incidence there (WHO, 1978).

Screening. Before 1972 nearly all sexually transmitted disease (STD) control activities at the state and local level in the United States were syphilis case finding and prevention efforts. The major dangers of gonorrhea were not generally recognized before 1972. Gonorrhea control consisted of diagnosis and treatment of individuals who came to public clinics. By 1974 nearly all state and local health departments had established federally-assisted gonorrhea control programs. A primary part of these programs involves culture testing large numbers of women for gonorrhea. Although some of the culture tests are for patients with symptoms who have come to clinics, many of the tests are for women without symptoms who are having a gynecologic examination. Adding a gonorrhea culture test to a pelvic examination is relatively inexpensive since the federal government pays for the laboratory analysis. The test is administered to women who are sexually active and in age groups where gonorrhea is present. **Each year since 1974 there have been over 8 million gonorrhea culture tests on women** of which between 4 and 5% were positive for gonococcal infection (CDC, 1979a). A goal of this extensive screening program is the identification and treatment of women with asymptomatic disease.

Some of the positive culture tests were diagnostic in the sense that they verified infection in women who had symptoms suggesting gonococcal infection or who had sexual contacts with infected individuals. Some of the positive culture tests were discoveries of the screening program in the sense that they occurred when there was no reason to expect infection or as the result of a routine pelvic examination. Yorke, Hethcote and Nold (1978) have estimated the effectiveness of the screening program in the United States in discovering infectives by using data from 1967-75. It was estimated that in 1973-75 approximately a third of the reported cases of gonorrhea in women were discoveries of the screening program and that approximately a tenth of all actual cases of gonococcal infections in women were discovered by the screening program. Reported case rates in men are largely independent of public awareness or screening campaigns. By assuming that the reported incidence in men is proportional to actual incidence in men, it was estimated that the 1974 screening program for

women caused the **actual male incidence** to decrease so that it **was approximately 20% below what it would have been without screening.** In Chapter 6, we use the estimates above to choose a parameter value. Specifically, we adjust a parameter value so that discovering (and treating) 10% of the infected women via the screening program yields a 20% decrease in male incidence.

Contact Tracing and Interviewing. Contact investigation or tracing attempts to identify contacts of known infectives and to encourage contacts to be checked as soon as possible. Intensive contact investigation is a very important control method for syphilis. Contact investigation for gonorrhea sometimes consists of educating known infectives about the seriousness of gonorrhea and asking them to encourage their contacts to be examined. Some clinics try to obtain identifications of known contacts, to communicate with the contacts by phone or in person and to encourage them to be examined for gonococcal infection. Early identification of infectives by contact tracing reduces their infectious periods and, consequently, can reduce the chance of transmitting the infection. During 1982 about 360,000 patients with gonorrhea were interviewed for sex partner referral, about 335,000 contacts were obtained, about 215,000 partners were examined and about 172,000 were treated either therapeutically or preventively (CDC, 1983). Many additional patients were counseled about their infection and advised to refer their sex partners for examination.

Vaccines. Although **no vaccine which prevents gonorrhea is now available,** many researchers are trying to develop a practical gonorrhea vaccine (WHO, 1978; NIAID, 1980; Marx, 1980; Shearer, 1983). One vaccine containing gonococcal pili elicited the production of antibodies both in blood and in the secretions of the urogenital tract, where they may prevent bacterial attachment (Marx, 1980). Another gonococcal pili vaccine stimulated the production of antibodies in the blood, but had only a slight, temporary effect on the secretory antibodies of the urogenital tract. Since there are about 1000 identifiable strains of gonococci with different pili, a gonorrhea vaccine would have to contain a variety of pili. The three exterior cellular components of a gonococcus are pili, proteins of the outer membrane and lipopolysaccharides so that some scientists suggest that a gonorrhea vaccine could be based on the latter two components (WHO, 1980). Because both gonorrhea and meningococcal meningitis are infections of mucosal surfaces and because the recently developed vaccine for meningitis only provides immunity for several months, it

is possible that a gonorrhea vaccine would only provide temporary immunity. Vaccines that produce permanent immunity are generally directed at viral diseases.

The search for a safe and effective gonorrhea vaccine continues. A recent news article (Shearer, 1983) indicates that the U.S. Army has field-tested an experimental vaccine for gonorrhea in Korea. Half of the 5000 volunteers in the study were injected with two doses of the Gonococcal Pilus Vaccine and the other half were given two doses of a placebo. The usefulness of this vaccine is unknown since the results of the study have not been announced.

1.4 Modeling Transmission Dynamics

In describing the transmission dynamics of a communicable disease, it is convenient to divide the population into disjoint classes whose sizes may change with time. The susceptible class S contains those can become infected, the exposed class E contains those who are in a latent period but are not yet infectious, the infective class I contains those who are infectious, and the removed class R contains those who have at least temporary immunity either from immunization or previous exposure.

There are several basic types of epidemiologic models (Hethcote, 1976; Hethcote, Stech and van den Driessche, 1981c). To model an epidemic (i.e., a sudden unusual increase in cases) of a disease for which recovery confers permanent immunity, SIR or SEIR models without vital dynamics (births and deaths) are appropriate. A sequence of letters such as SEIR describes the movement of individuals between the classes: susceptibles become latent, then infectious and finally recover with immunity. To model diseases which confer permanent immunity and which are endemic (i.e., always present) because of births of new susceptibles, SIR or SEIR models with vital dynamics are suitable. Models of SIRS or SEIRS type are used to model diseases which remain endemic because the immunity is only temporary. Diseases for which recovery does not confer immunity are described by SIS or SEIS models.

Gonorrhea has three striking epidemiological characteristics which must be incorporated into a model. **First**, as described in section 1.2, **gonococcal infection does not confer protective immunity** so that individuals are susceptible again as soon as they recover from infection. Indeed, this lack of protective immunity makes gonorrhea very different from other diseases such as measles, mumps, rubella, chickenpox, poliomyelitis, diphtheria, whooping cough, and tetanus.

Gonorrhea is a particularly interesting disease to model precisely because infection does not confer protective immunity. **Second, individuals who acquire gonorrhea become infectious within a day or two** so that the latent period is very short compared to the latent period of about 12 days for measles, 15 days for chickenpox, and 18 days for mumps. Indeed, the latent period for gonorrhea is short enough so that it is not necessary to include an exposed class in a model for gonorrhea. **Third, the seasonal oscillations in gonorrhea incidence are very small** (less than 10%). In contrast, the incidences of diseases such as influenza, measles, mumps and chickenpox often vary seasonally by factors of 5 to 50 or more. Thus, models which use constant values for parameters such as the contact rates provide good approximations for gonorrhea.

Because the three characteristics of gonorrhea described in the previous paragraph seem to imply that SIS models with constant parameter values are suitable for modeling gonorrhea, we now investigate this issue further. Time delays can be introduced to model the time required for a person to pass from one disease state to another. Since periodic solutions can arise in SIRS models with time delays even though the parameter values are constant (Hethcote, Stech and van den Driessche, 1981a), one might wonder if periodic solutions can arise in SEIS models with time delays and constant parameter values since SEIS models are also cyclic with 3 classes; however, it has been shown that these SEIS models have stable equilibrium points so that they do not have periodic solutions arising by Hopf bifurcation (Hethcote, Stech and van den Driessche, 1981b). Indeed, for both SEIS and SIS models with constant parameter values, time delays do not change the general nature of thresholds or asymptotic stability; in all constant parameter models (i.e., without seasonal variation) the disease either dies out or approaches an endemic steady state (Cooke and Yorke, 1973; Hethcote, Stech and van den Driessche, 1981c). Because the essential behavior of SEIS models is the same as for SIS models, SIS models with no latent period are accurate approximations to SEIS models with very short latent periods. Since time delays do not affect the asymptotic behavior and since we will be interested in the behavior near the equilibrium points or in how the equilibrium points change when parameter values or control procedures change, the ordinary differential equation models without time delays are sufficiently general (Hethcote and Tudor, 1980). In conclusion, **SIS models** using ordinary differential equations without seasonal variation and without time delays **are satisfactory for describing the transmission**

dynamics of gonorrhea.

The first mathematical model explicitly for gonorrhea was developed by Cooke and Yorke (1973). They studied the asymptotic behavior of solutions of an integral equation model for a single homogeneous population which used time delays to represent variation in the infectious period. Cooke (1976) considered the effects of immigration on this model. Reynolds and Chan (1974) considered a linear differential equation model for gonorrhea, estimated the parameters, and projected the prevalence for women and men, both with and without terms modeling control procedures. Because the model is linear, the prevalence can grow exponentially without saturating the populations. Constable (1975) discussed the problems of gonorrhea modeling and formulated a model with five groups for each sex. Hethcote (1973) showed that all endemic solutions of an ordinary differential equation SIS model with a periodic contact rate approach an explicitly given periodic solution. A two group differential equation model for gonorrhea has been analyzed by Hethcote (1974,1975,1976). Bailey (1975, Chapter 11) showed how SIS models developed for other diseases can be used for gonorrhea.

A model for gonorrhea with an arbitrary number of interacting groups was formulated and analyzed by Lajmanovich and Yorke (1976) and Nold (1980). The section on gonorrhea in the differential equations text by Braun (1975) is based on material (used without acknowledgment) from a preprint of the paper of Lajmanovich and Yorke (1976). Aronsson and Mellander (1980) showed that if the Lajmanovich and Yorke model is modified to include seasonal variation in the contact and removal rates, then in the endemic case, there is a nontrivial periodic solution which is globally asymptotically stable. Nallaswamy and Shukla (1982) modified the Lajmanovich and Yorke model to include spatial diffusion and analyzed the stability of the endemic equilibrium state. Thieme (1982) showed that the Lajmanovich and Yorke global stability results still hold if short periods of incubation or immunity are included. Hirsch (1984) obtained the Lajmanovich and Yorke global stability results for a more general model.

Yorke, Hethcote and Nold (1978) argued that gonorrhea prevalence responds rapidly to changes in social behavior and control procedures. They also showed that the equilibrium prevalence moves as social and medical conditions change. They introduced concepts such as saturation, preemption and the core subpopulation into gonorrhea analysis. These results are described in more detail and justified mathematically in this monograph. Kemper (1978,1980) studied SIS models for

one population with asymptomatics (infectives without symptoms) and with superspreaders (highly infectious individuals). Bailey (1979) reviewed the current state of modeling gonorrhea and formulated some new models with symptomatics and asymptomatics. The local stability of these models was analyzed by Wichmann (1979).

Kramer and Reynolds (1981) used a stochastic computer simulation model to evaluate gonorrhea vaccination and other control strategies. Hethcote, Yorke and Nold (1982) used an eight group model for gonorrhea to compare the effectiveness of six prevention methods for gonorrhea involving population screening and contact tracing of selected groups. The population was divided according to sex, sexual activity and symptomatic or asymptomatic infection. These results are presented and explained in Chapter 6. A news article about the results in this paper of Hethcote, Yorke and Nold (1982) appeared in Nature (May, 1981). Cooke (1982) proved global asymptotic stability for an SIS model involving symptomatics and asymptomatics. See Cooke (1984) for a survey of infectious disease models with asymptomatics.

1.5 The Contact Number and the Infectee Number

The contact number for an infectious disease in a population is defined as the average number of adequate contacts of a typical infectious person during the infectious period (Hethcote, 1976). An adequate contact is a direct or indirect contact that is sufficient for transmission of infection if the individual contacted is susceptible. The concept of an adequate contact is necessary since transmission of infection sometimes does not occur during sexual intercourse between an infective and a susceptible. Moreover, the probability of transmission from an infectious man to a susceptible woman is greater than the probability when the roles are reversed. If all people contacted were susceptible, then the contact number would be the average number of people infected by one infective during the infectious period. The contact number for gonorrhea depends on the sexual behavior of the population being considered. The contact number has also been called the reproduction rate (Dietz, 1975).

Some of the adequate contacts of infectious individuals do not result in transmission of the infection since these contacts are not with susceptibles. An infectee is someone infected by an adequate contact. The infectee number for an infectious disease is the average number of actual transmissions by an average infective during the infectious period. The infectee number may vary with time, for example, seasonally. The infectee number is the product of the contact

number and the susceptible fraction at the given time. The infectee number has also been called the replacement number (Hethcote, 1976), the infector number (Yorke, Hethcote and Nold, 1976) and the reproduction rate (Anderson and May, 1982).

A basic principle for all diseases is that **the infectee number is one when the disease is at an endemic equilibrium** (i.e., a positive steady state) (Hethcote, 1976; Yorke, Hethcote and Nold, 1978; Nold, 1979). This principle is an average result since some infectives might infect several susceptibles and other infectives might infect no susceptibles. It is assumed that each transmission is the result of a person to person contact (i.e. there are no vectors) and that the population is closed (i.e., there is no immigration of infected people). The principle above is intuitively reasonable since if the average infective passed the disease on to more than one susceptible person, then the prevalence would increase. If the average infective passed the disease on to less than one individual, the prevalence would decrease.

One consequence of the principle above is that at an endemic equilibrium the average infective has two adequate contacts during the course of the infection: a contact with an infector or source of the infection and a contact with an infectee to whom the infection is transmitted. Thus the average person with gonococcal infection would have at least two sex partners during the period of infection. See Yorke, Hethcote and Nold (1978) for a comparison of this theoretical result with some clinical survey data.