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Arthropod-borne encephalitis viruses and water resource developments*

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ABSTRACT.

The distribution of the arthropod-borne encephalitis viruses is presented, and their ecology in relation to water resource developments is discussed. Specific examples are given of the relationships between water resource developments and western equine encephalitis (WEE), St. Louis encephalitis (SLE), West Nile (WN), Murray Valley encephalitis (MVE), and Japanese encephalitis (JE) viruses. The zoonotic character of the virus cycles is stressed, and the activities and cultural habits of man which favor propagation of the viruses is discussed.

KEY WORDS : arbovirus diseases – epidemiology – ecology.

RÉSUMÉ.

L'auteur présente la répartition des virus à encéphalites et discute leur écologie en fonction du développement des ressources en eau.

Il donne des exemples spécifiques des relations entre le développement de ces ressources et les virus de l'Encéphalite Equine de l'Ouest (WEE), de l'Encéphalite de Saint-Louis (SLE), de West Nile (WN), de l'Encéphalite de la Murray Valley (MVE) et de l'Encéphalite Japonaise (JE).

L'auteur insiste sur le caractère de zoonose des cycles viraux ainsi que sur les activités et les coutumes humaines qui peuvent favoriser la propagation des virus.

MOTS CLÉS : arboviroses – épidémiologie – écologie.

INTRODUCTION.

The most recent revision of the "International Catalogue of Arboviruses Including Certain Other Viruses of Vertebrates" lists 359 viruses (Berge, 1975). Most of these viruses are maintained in nature in transmission cycles involving arthropods. Among the arboviruses which cause disease in man are some with neurotropic affinities which cause the clinical syndrome encephalitis. All of these encephalitis viruses are maintained in nature in zoonotic cycles. The arthropod vectors are mosquitoes or ticks, but usually not both for the same virus. Public health and veterinary problems arise when man and his domestic animals intrude into ecosystems where these zoonoses exist, and particularly when man radically alters the environment in a manner which favors increased arbovirus activity. Prime examples of man-made environmental changes which may result in an increase in the incidence of encephalitis virus transmission in an area are water impoundments and irrigation schemes.

ALPHAVIRUSES.

The distribution of alphaviruses which cause encephalitis in man and horses is shown in Figure 1. The boundaries for virus distribution, presented in this figure and those which follow, represent the extreme limits of known or presumed virus activity. Each virus does not necessarily occur continuously throughout the range indicated. Similary, the delineation of epidemic zones represents an approximation of the actual situation. A more general discourse on the distribution of the arthropod-borne viruses has been presented by Theiler and Downs (1973), and specific information for individual viruses can be found in Berge (1975).

All of the alphaviruses which cause encephalitis in

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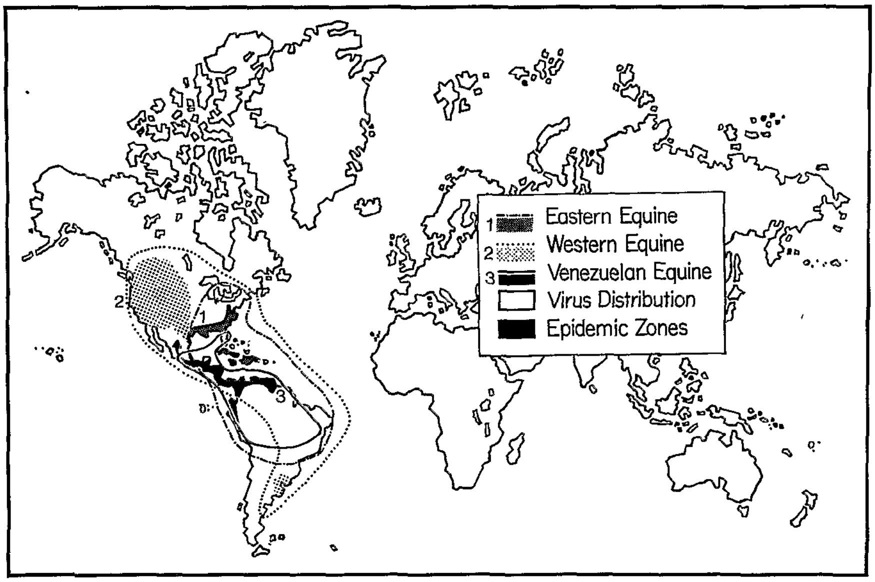

FIG. 1. — Distribution of Alphaviruses Causing *Encephalitis* in Man.

man are transmitted by mosquitoes; however, only western equine encephalitis (WEE) is usually associated with water resource developments, particularly irrigated agriculture. During the summer season when epidemics occur, WEE virus is cycled principally between *Culex tarsalis* mosquitoes and passerine birds (Reeves and Hammon, 1962). In some areas, such as the Sacramento Valley of California, the virus may be cycled between *Aedes melanimon* and the blacktail jackrabbit, *Lepus californicus* (Hardy and Bruen, 1974). West of the 100th meridian, *Culex tarsalis* also is the principal vector of a flavivirus, St. Louis encephalitis (SLE) virus, and many of the generalization which follow concerning the relationships between *C. tarsalis,* irrigated farm and ranchlands, and WEE, apply equally well to SLE in the western United States.

Jenkins (1950) outlined the distribution of *C. tarsalis* in North America. Few significant changes in distribution have been noted since the time of his publication. In the United States this mosquito generally becomes abundant only in areas where irrigation schemes assure the presence of extensive and relativity dependable breeding habitats. Long-term studies by Reeves and Hammon (1962) in Kern County, California, demonstrated that over 80 % of *C. tarsalis* larval sources were in sunlit ground pools, almost all of which man-made with the exception of flooded riverside areas. Currently, in excess of 160,000 hectares of rice in the Great Central Valley of California also provide suitable breeding habitat for this mosquito.

The Center for disease Control (CDC) conducted studies on the ecology of arboviruses and their vectors in the irrigated high plains, or Llano Estacado, of northwestern Texas from 1953 to 1973. Stream drainage is poorly developed in this area, and shallow circular basins (playa lakes) occur more or less uniformly on an average of about one per 1.6 km^2. The economy of the area is basically agrarian, and most of the arable land is cultivated. Deep-weel irrigation provides the necessary water, and grain sorghum and cotton are the principal crops. *C. tarsalis* is the major vector of both WEE and SLE viruses in the area (Hayes *et al.,* 1967). Harmston *et al.* (1956) found that playa lakes accounted for approximately 75 % of mosquito production in the irrigated high plains and that about 87 % of the water in larval habitats consisted of waste and residual irrigation water.

The situation in Hale County, Texas, provides an excellent example of how man-made environmental changes can favorably influence encephalitis virus transmission. *C. tarsalis,* an efficient vector of both WEE and SLE viruses, finds ample breeding habitat in waste and residual irrigation water. This mosquito generally prefers to feed on birds, but also bites man an horses (Hayes *et al.,* 1973). The house sparrow (*Passer domesticus*) nestling is an excellent vertebrate host for WEE virus and circulates the virus in the blood at high titers for periods sufficiently long to infect vector mosquitoes (Holden *et al.,* 1973a and 1973b). The house sparrow is not native to the United States, but was first introduced from England in 1850; subsequent introductions were made, and the species probably extended its range into the Texas High Plains sometime between 1886 and 1900 (Robbins, 1973). It is now well adapted to the area, and its breeding season coincides with the period of epidemic encephalitis virus activity (Mitchell *et al.*, 1973a). The house sparrow is the predominant avian species in Hale County (Mitchell *et al.*, 1977). This granivorous species benefits from irrigated agriculture since the extensive acreages of grain sorghum provide a ready food supply, and grain storage barns and introduced plantings of shade trees in this naturally barren area provide shelter and nesting sites.

Figures 2 and 3 illustrate the relationship between the

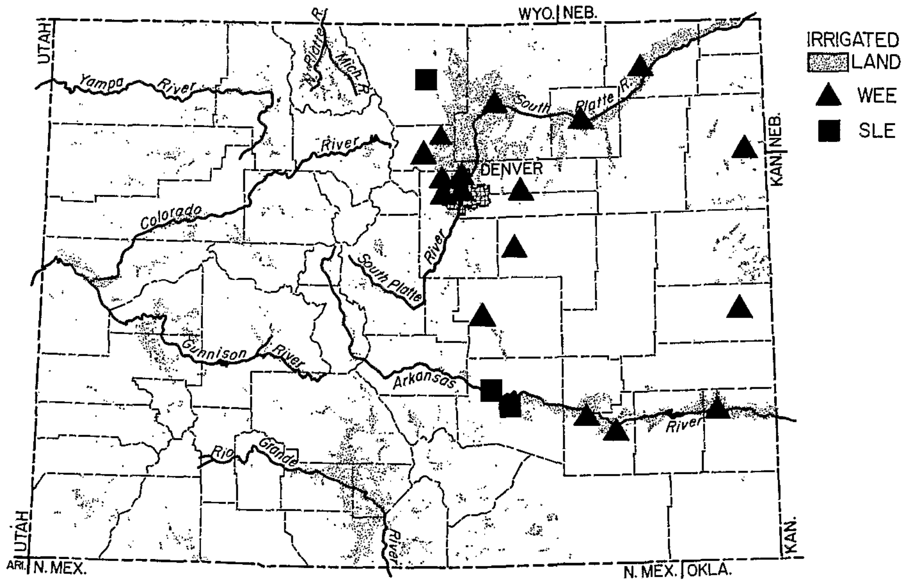

FIG. 2. — Distribution of Human Cases of WEE and SLE in Colorado during 1975.

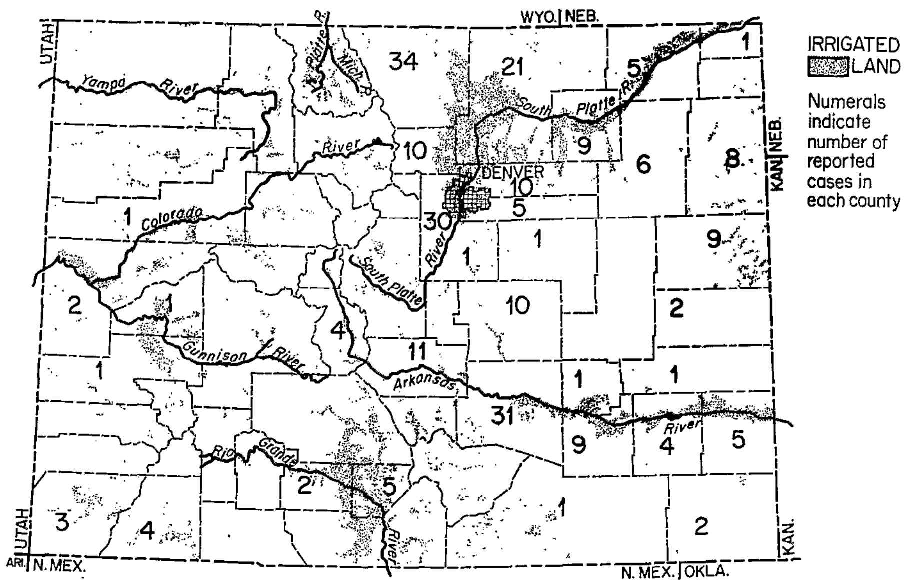

FIG. 3. — Distribution of Equine Cases of WEE in Colorado during 1975.

distribution of irrigated land in the state of Colorado during 1975 and distribution of human cases of WEE and SLE and equine cases of WEE. There were 20 confirmed human cases (17 WEE and 3 SLE) and 250 suspected equine cases (all WEE) of arthropod-borne encephalitis in Colorado during the year. The relationship between the distribution and abundance of *C. tarsalis* in Colorado and the distribution of irrigated land can be deduced by inference since this mosquito is the principal vector of both WEE and SLE viruses in the state. Similar data could be presented for many areas in the western United States where *C. tarsalis* is the vector of these viruses.

McLintock (1976) pointed out that in the prairies of western Canada, *C. tarsalis* may breed in a wider variety of larval habitats. This is also the case in some areas of the United States, and during certain years, rainfall and runoff from winter snowpack in the mountains may be of paramount importance in flooding breeding habitats. Nonetheless, epidemic encephalitis generally occurs only when natural breeding habitats are supplemented by those associated with irrigated land. For example, during 1975 unusually heavy rainfall caused flooding of the Red River Valley in North Dakota and Minnesota in the United States, and in Manitoba, Canada. This resulted in unusually dense *C. tarsalis* populations in these agricultural areas in the United States, and 65 human cases of WEE were confirmed in North Dakota and Minnesota (CDC, 1976). In Manitoba 14 WEE cases were documented; half the cases were seen in Winnipeg (4 of the 7 were located near the Assiniboine River), and all but 1 of the rural cases occurred in the Red River Valley (Waters, 1976).

FLAVIVIRUSES.

The distribution of the mosquito-borne flaviviruses which cause encephalitis in man is shown in Figure 4. With the exception of Ilheus virus, which occurs in South and Central America and does not appear to be an important cause of human disease, each of these viruses is affected to some extent by water resource developments.

St. Louis encephalitis virus activity has been reported from southern Canada to Argentina. The virus is cycled between *Culex* mosquitoes and wild birds during the epidemic season. The epidemic zone includes much of the United States, and, during 1975, extended into Ontario, Canada (McLintock, 1976). The year 1975 was one of unprecedented SLE virus activity in the United States. There were 1,941 confirmed and presumptive human cases detected in 29 states and the District of Columbia (CDC, 1976). Most of the cases occurred in the Ohio and Mississippi River drainages, with the states of Illinois, Indiana, Ohio, and Mississippi being most seriously affected (CDC, 1976).

As indicated above, *C. tarsalis* is the principal vector of SLE in the western United States where epidemics generally are rural in character. During 1975, however, most of the cases occurred in urban areas east of the

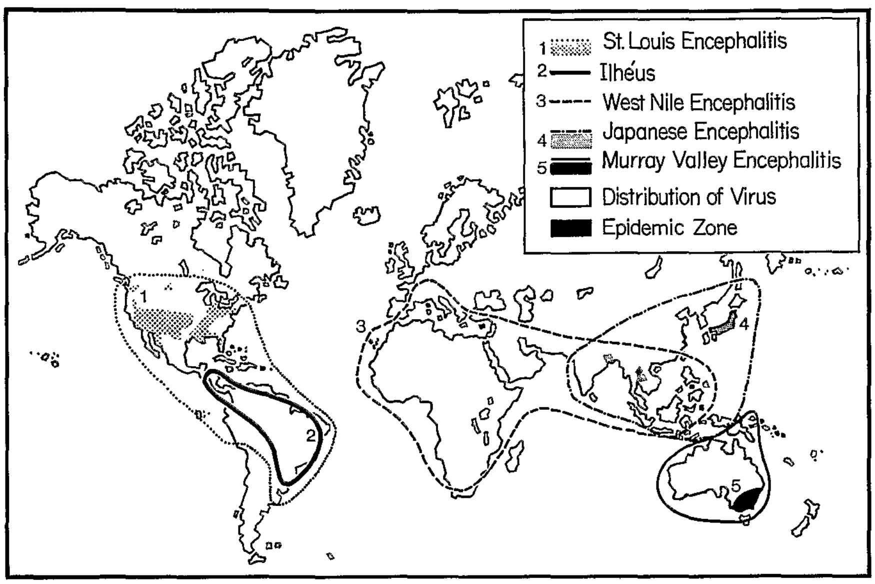

FIG. 4. — Distribution of Mosquito-Borne Flaviviruses Causing *Encephalitis* in Man.

100th meridian where members of the *Culex pipiens* complex are the usual vectors. The tropical mosquito *Culex nigripalpus* also has been incriminated as a vector of SLE virus during previous outbreaks in Florida and Jamaica. In addition, CDC investigators have evidence that species other than those listed above may have been involved in some of the 1975 outbreaks.

The distribution and abundance of mosquitoes of the *C. pipiens* complex are closely related to poor sanitation and inadequate drains and sewage systems, particularly in urban areas. It is relevant that in developing countries, villages and settlements often are built along the shores of water impoundments, and inadequate sanitation immediately makes such communities suitable breeding habitats for mosquitoes of the *C. pipiens* complex. The same can be said for satellite areas or shantytown settlements built out into agricultural lands along the marginal areas of cities (Gratz, 1973).

West Nile (WN) virus activity has been detected throughout much of Africa through southern Europe, and into southeast Asia. The basic transmission cycle during the epidemic season involves *Culex* mosquitoes and wild birds. Clinical manifestations in man range from a mild febrile illness in children to severe dengue-like infections and occasional encephalitis in elderly patients. Infected horses also may develop encephalitis. Taylor *et al.* (1956) conducted intensive studies on the ecology of WN virus in Egypt. In the Sindbis Sanitary District, an agricultural area about 30 km north of Cairo in the Nile Delta, *Culex univittatus* appears to be the most important vector, and the house sparrow, hooded crow, and pigeon are important vertebrate hosts. West Nile virus also has been isolated from a tick, *Argas hermanni,* in the Nile Delta (Schmidt and Said, 1964). Hoogstraal (1973) indicated that the virus can be recovered throughout the year from this tick collected in Egyptian pigeon houses. There is speculation that this African bird argasid may be involved in the overwintering maintenance of WN virus. Hoogstraal (*op. cit.*) also referred to the recovery of WN virus from immature *Hyalomma marginatum marginatum* in the Volga delta, U.S.S.R.

Examination of the ecology of WN virus and its vector, *Culex modestus,* in the Camargue area of the Rhone delta in southern France offers an interesting example of an instance where increased irrigation and extension of rice culture has led to an increase in virus activity (Hannoun *et al.,* 1964). Rice acreage increased from 200 to 20,000 hectares between 1942 and 1960 (Surtees, 1975). Cultivation of the land and concomitant desalinization of surface water was followed by an increase in the abundance of *C. modestus.* This in turn was followed by the detection of WN fever in man and an increasing number of cases of encephalitis in horses.

Murray Valley encephalitis (MVE) virus apparently is endemic in northern Australia and periodically extends into southern areas where it causes epidemics, especially in the Murray Basin. During the 1974 epidemic an estimated 60 cases occurred involving all of the mainland states and the Northern Territory (Stevenson, 1975). Again, the greatest concentration of cases was in the Murray Valley, particularly in northern Victoria, where 29 cases were reported. Virus activity also has been detected in New Guinea (Doherty, 1974). The virus is maintained in a mosquito-bird cycle during the epidemic season, and *Culex annulirostris* is believed to be the principal vector. The larval habitats of this mosquito include grassy and weedy pools and hoofprints along the margins of rivers, grassy or weedy margins of earthern drainage channels, adjacent seepage pools, flooded pastures, and shallow reedy or grassy swamps formed by irrigation drainage (Reeves *et al.,* 1954).

The completion of the Ord River Dam and the anticipated expansion of irrigated agriculture on the Kimberley Plateau in Western Australia undoubtedly will affect the activity of MVE virus in that region. *C. annulirostris* is the dominant mosquito in the area and can be expected to profit from expansion of irrigated agriculture. Six arboviruses, including MVE virus, have been isolated from *C. annulirostris* in the Ord River area (Stanley, 1975).

Japanese encephalitis (JE) virus occurs widely throughout much of Asia and adjacent islands, and recent outbreaks have occurred in Japan, Korea, Taiwan, Thailand, and India. Mosquitoes of the *Culex vishnui* complex are the principal vectors; however, *Culex gelidus* may act as an enzootic vector in Malaysia, Sarawak, and Thailand, and *Culex fuscocephalus* may do so in Thailand and Taiwan. All of these mosquito species have one thing in common-they breed prolifically in paddy fields. To appreciate the magnitude of the problem in terms of mosquito habitat, one need only recall that rice is the staple food for much of Asia's population, which makes up more than one-half of humanity. The International Rice Research Institute estimates that approximately 13.3 million hectares of land in Asia are devoted to rice culture.

Basic studies on the ecology and epidemiology of JE virus in and around Tokyo by Scherer *et al.* (1959 a, b, c, d, e) and Buescher *et al.* (1959 a, b, c) incriminated *Culex tritaeniorhynchus* as the principal vector in that area. This mosquito breeds in rice fields and feeds on large domestic animals including swine, water buffalo, and cattle, but also feeds on birds and man. Black-crowned night herons, egrets, and swine serve as amplifying hosts for the virus during the epidemic season. A decrease in the intensity of JE epidemics in Japan during recent years, particularly in the Tokyo area, has been ascribed to increased urbanization and an intensive JE vaccination program (W.H.O., 1969).

In Taiwan, *Culex annulus* and *C. tritaeniorhynchus* have been incriminated as JE vectors (Wang *et al.*, 1962 a; Hurlbut, 1964; Detels *et al.*, 1970 and 1976; and Okuno *et al.*, 1973), and the virus has been isolated from *C. fuscocephalus* (Wang *et al.*, 1962 b; and Detels *et al.*, 1970). A Taiwan strain of *C. fuscocephalus* also has been shown to transmit JE virus experimentally (Okuno *et al.*, 1975 a). Interpretation of the results of the earlier studies is complicated by the fact that mosquito pools treated as *C. tritaeniorhynchus* may have contained *C. annulus*. These two species are very similar morphologically and are difficult to separate in the adult stage. The weight of evidence from the more recent studies, published during 1970 and subsequently, suggests that *C. annulus* is by far the most important vector of JE in northern Taiwan.

Again, we have an intricate web of cultural and dietary habits of a people on the one hand, and the ecological requirements of a virus and vector on the other, which together provide optimum conditions for virus transmission. More than 500,000 hectares of land in Taiwan are devoted to paddy cultivation, the major larval habitat of *C. annulus*. Okuno *et al.* (1975 b) have shown that the geographical distribution of JE cases in Taiwan during 1968-1971 corresponds very closely with the distribution of the rice growing areas. *C. annulus* is the predominant vector species in northern Taiwan (Mitchell and Chen, 1973), and the species feeds preferentially on swine (Mitchell *et al.*, 1973 b), the principal amplifying vertebrate host of JE virus during the epidemic season (Okuno *et al.*, 1973). Pork is a favorite food of the people of Taiwan, and it is estimated that there is an annual turnover in the swine population of about 3,000,000. This large turnover assures a ready supply of susceptible vertebrate hosts each year. In rural areas of Taiwan, man and domestic animals live in close proximity to each other and to paddy fields. Therefore, during the epidemic season, spillover in transmission of JE virus from the *C. annulus*-swine cycle to man is not only relatively easy, it is assured.

Recent epidemics of JE in West Bengal, India (Chakravarty *et al.*, 1975; Chatterjee and Banerjee, 1975; and Ghosh *et al.*, 1975), and in the Chiangmai Valley, Thailand (Grossman *et al.*, 1973 a, b, c; Grossman *et al.*, 1974; Gould *et al.*, 1974; and Johnsen *et al.*, 1974) appear to have followed a somewhat similar epidemiological pattern. Outbreaks in both areas were associated with rice cultivation and swine rearing.

The epidemiology of JE differs from tropical areas where transmission may occur year around to temperate areas where human cases are reported only during a relatively brief period of 1 or 2 months. Simpson *et al.* (1976) suggested that in Sarawak the pig acts as a maintenance host of JE virus throughout the year in a cycle involving *C. gelidus*, and as an amplifier host towards the end of the year in a cycle involving *C. tritaeniorhynchus*. The population density of *C. tritaeniorhynchus* in Sarawak is profoundly affected by rice culture practices. Grossman *et al.* (1974) proposed that the Chiangmai Valley, Thailand, which lies at 17° to 20° N. latitude, may be geographically situated between the two major zones of JE virus transmission.

The distribution of tick-borne flaviviruses which cause encephalitis in man is shown, for purposes of completeness, in Figure 5. Since the ecology of these viruses generally is not closely related to water resource developments, they will not be considered further in this report.

BUNYAVIRUSES.

The distribution of the bunyaviruses which cause encephalitis in man is shown in Figure 6. Among those listed, Congo and Thogoto viruses are tick-borne and the remainder are transmitted by mosquitoes. Although California encephalitis (CE) virus was first isolated in 1943 and was associated with human disease in 1945 (Hammon and Reeves, 1952), this subtype is not known to be of significant public health importance. The other subtype listed, California La Crosse (LAC), has been responsible for several outbreaks of human illness in the northcentral and midwestern United States (Henderson and Coleman, 1971). The major vector of the LAC subtype is a treehole mosquito, *Aedes triseriatus*, and consequently is unaffected by water resource developments.

OTHER STUDIES.

In addition to the studies referred to above, reference should be made to the joint project undertaken by the Kenya Ministry of Health and the British Medical Research Council to study the effects on arbovirus activity of the West Kano irrigation scheme located close to the shore of Lake Victoria (Simpson, 1975). These studies were initiated in 1971 and have shown changes in the abundance of mosquitoes in an adjacent pilot rice scheme; however, no significant changes in arbovirus activity have been demonstrated to date.

CONCLUSIONS.

A number of public health and veterinary problems may arise through man's mismanagement of water and his inadvertent fostering of enzootic arbovirus cycles. The relationships often are complex, and solutions to

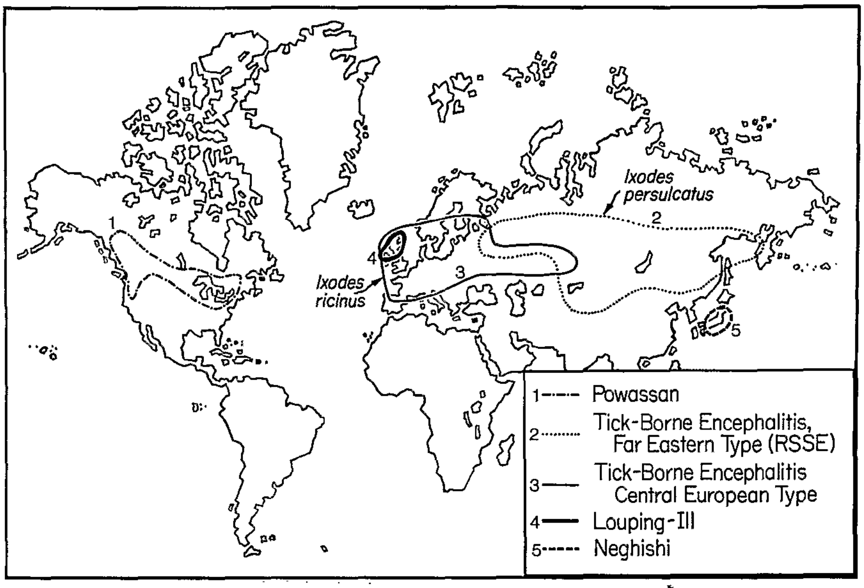

FIG. 5. — Distribution of Tick-Borne Flaviviruses Causing *Encephalitis* in Man.

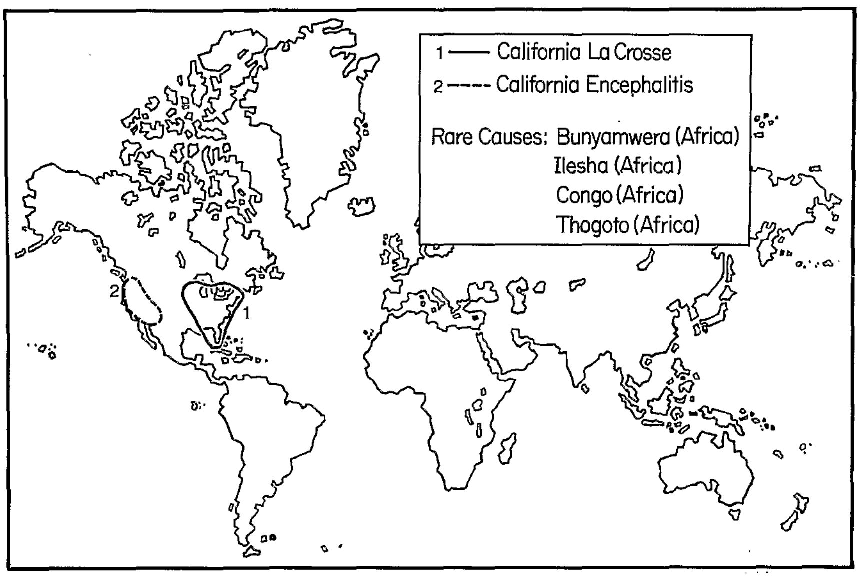

FIG. 6. — Bunyaviruses Causing *Encephalitits* in Man.

the problems may not be readily apparent. For example, *Culex* mosquitoes such as those in the *C. vishnui* group probably evolved in freshwater swamps, and the widespread cultivation of rice has greatly expanded their breeding habitat. Mosquito control in areas with vast acreages of rice is at best a formidable undertaking, and may be impossible because of political constraints, economic considerations, and the inadequacy of current mosquito control technology. More research is needed, and, where possible, careful consideration should be given to planning for the prevention and control of vector mosquito problems before they are created.

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