Ingram (1959), W.

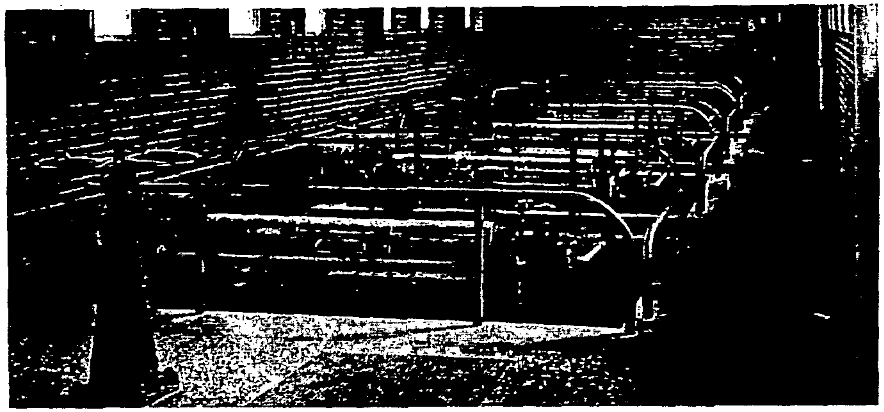

Fig. 7. Microstrainer Installation at Belleville, Ont.

These four microstrainer units are installed ahead of rapid sand filters and have been effective in removing the heavy algal growth to which the Bay of Quinte, Lake Ontario, is subject.

the most common use for microstraining is before slow sand filtration. Although it is true that a greater proportion of the early installations, and many presently being installed, were for that purpose, it is also true that over the last few years microstraining, as the sole filtration process, has been the principal application in both public and industrial supplies. An increasing number of microstraining units are also being used for effecting primary treatment ahead of rapid sand filters in a manner similar to installations in front of slow sand filters.

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37

Journal of the American Water Works Association (1959) 51(3): 363-370

SW 344

Asiatic Clams as Potential Pests in California Water Supplies

William M. Ingram

A contribution to the Journal by William M. Ingram, Biologist, Robert A. Taft. San. Eng. Center, USPHS, Cincinnati, Ohio.

DIFFICULTIES caused by Asiatic clams, *Corbicula fluminea* (Muller) (Fig. 1), in California irrigation systems have been reported. These organisms have been troublesome in the Coachella Valley in Southern California and at the Tracy Pumping Station in central California. Concern has also been expressed by the Metropolitan Water District of Southern California, which has not yet encountered problems but has foreseen possible clam difficulties. With further development of irrigation and potable water supplies, Asiatic clams are seen as potential pests and a threat of continuing nuisance by those who are charged with maintenance of water projects.

Distribution

These clams have been found well established in natural waters where present nominal uses have not yet brought them into intimate contact with man. The Asiatic clam was reported in North America in 1948 (*1*). From collections then available, the Asiatic clam was listed as occurring in California at the following localities: the north end of Sherman Island at north end of Mayberry cut in the "Old Sand Bank," Sacramento County; Frank's Tract near Oakley, junction of Broad Slough and the Sacramento River, near the mouth of the Mokelumne River; the Sacramento River near Isleton; Shad Landing, San Joaquin River; the Middle River at Santa Fe Railroad Ferry, San Joaquin County; Snodgrass Slough; and a drainage ditch into Sycamore Slough near Reveal Landing, South Fork of the Mokelumne River, San Joaquin County. California localities subsequently reported to the author are: the Colorado River Aqueduct near Gene Pumping Plant; Mecca from an irrigation outflow channel discharging into the Salton Sea; Rock Slough, Contra Costa County; an irrigation ditch 12 mi east of Los Banos, Merced County; vicinity of Bakersfield, Kern County; San Joaquin River as far as Patterson; Antioch to the Feather River; the Contra Costa and Delta-Mendota canals of the California Central Valley Project; and Modesto, Tuolumne River, Stanislaus County.

In 1948 the clam was also found in the Columbia River in Pacific County, Wash., and in the Willamette River, Ore. Present information is that clams are being taken from Lake Mead on the Colorado River, and from water supplies of Phoenix, Ariz. In the US National Museum the author has examined two specimens from Phoenix which bear the accession date of Nov. 18, 1954. In 1958 Dundee and Dundee (*10*) reported the Asiatic clam from an irrigation canal behind the Desert Plant Botanical Garden (Papago Park) in Phoenix, Ariz. They refer to earlier records of its distribution in the West based on mimeographed minutes of the Conchological Club of Southern California. In the Pacific Northwest, recent information

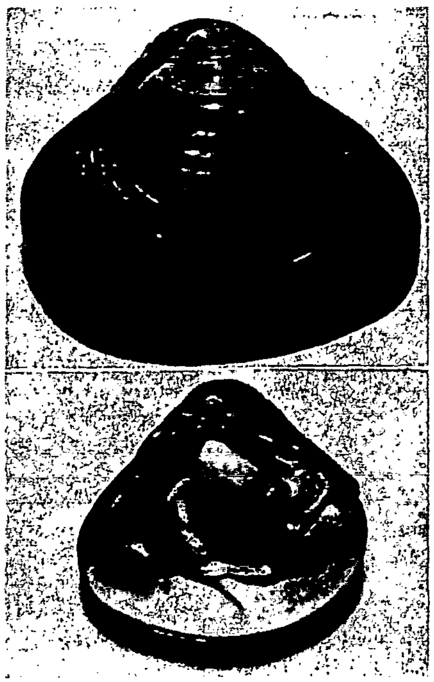

Fig. 1. Asiatic Clam

The actual length of this specimen was approximately 31 mm. Upper photograph, exterior view; lower, interior view.

states that clams occur on both the Oregon and Washington sides of the Columbia River at Bonneville, and in the Snake River on the Washington–Idaho border. The earliest collection date for California specimens available to the author is 1946, where they were found in an irrigation ditch 1.6 mi east and 2.2 mi north of a road crossing over Potato Slough at Terminus on Lodi-Isleton Highway. The earliest collection date from Washington is 1938 in the Columbia River, 2 mi east of Knappton. The specimens bearing these dates are housed in the California Academy of Sciences.

Information is still not available to indicate how widely the Asiatic clam is distributed in the Western States, although it is 10 years since their presence was recorded in published literature (*1*). This article establishes this clam as an economic pest, and water development agencies may therefore wish to investigate thoroughly its distribution lest it become related pestiferously to planned projects.

Nuisance in Coachella Valley

In 1953 C. S. Hale, general manager of the Coachella Valley County Water District, Coachella, Calif., stated in correspondence that an apparently serious infestation of *Corbicula fluminea* had developed in the water district's underground distribution system. Irrigation water is taken from the Colorado River at Imperial Dam, transported through 123 mi of open canal, and distributed through approximately 500 mi of underground pipe. Accumulation of live clams and clam shells causes serious impairment of water delivery at farmers' turnout valves, at ends of laterals, and in irrigation sprinkler systems. Clams were appearing in irrigation water in Riverside County and Imperial Valley distribution systems.

Further correspondence with Hale in March 1955, stated that the clam population had greatly subsided in the summer of 1954, and that there had been little trouble as compared to 1953. No explanation was offered for the subsidence, except that water temperatures had probably been a little higher. In 1954, owing to weed debris, most of the canal water was diverted to a settling basin about 2 mi long. From this basin the water was returned to the canal at a somewhat higher temperature, which resulted from the shallowness of the basin.

In January 1958, correspondence from Lowell O. Weeks, general manager and chief engineer of the Coachella Valley County Water District, reviewed the troubles cited in Hale's letters and brought the clam situation up to date. Weeks stated that an 8-ft diameter lateral is opened each January at its distribution point. In 1953, perhaps 100–200 clams were found in this structure. In 1954 about 3 cu yd of clams were removed, but during the summer the clam nuisance to farmers greatly subsided. In January 1955 only about ½ cu yd had accumulated in the lateral. Succeeding seasons have revealed only slight accumulations in this structure and no farmers have complained. Weeks commented that 86 mi of unlined canal, which brings water into the Coachella Valley from the All-American Canal, was emptied of water in November 1957 after approximately 10 years of continuous flow. It was noted that various sections were heavily infested with clams, and that for a distance of ½ mi the bottom appeared to be heavily graveled with clams. This observation led him to believe that recurrence of the 1953 summer clam infestation was entirely possible if and when the correct conditions occurred. No control measures were mentioned in the correspondence, other than manual removal of clams. The single explanation proffered for the subsidence of clam nuisances was the 1954 diversion of canal water into the settling basin, where increased water temperature may have reduced clam populations.

Metropolitan Water District

In January 1958, Lee Streicher, chief chemist of the Metropolitan Water District of Southern California, stationed at LaVerne, Calif., wrote that an infestation of fresh-water clams had recently been discovered in Colorado River water near the intake of the district's aqueduct system. These clams were identified as *Corbicula fluminea.* Specimens sent to the author were collected on Dec. 14 from the Colorado River aqueduct near Gene Pumping Plant. No trouble was then reported as being caused by the clam, but concern was expressed as to the possible effects on the carrying capacity of pipelines and possible damage to the impellers of large centrifugal pumps, should the clams be dislodged from the invert of the pipe and drawn into the pumps.

The experience of the Coachella Valley County Water District has demonstrated that the Asiatic clam can disrupt flow through pipe. With time, large accumulations of shells could also affect flow in large pipe, if the 3 cu yd of clams that accumulated in the 8-ft lateral of the Coachella irrigation system represented the annual volume entering into large distribution pipe. Difficulties that are caused by the fresh-water, zebra clam, *Dreissensia polymorpha,* in reducing the diameter of 24-in. mains in England have been described by Clarke (*2*) and summarized by the author (*3*). Fortunately, this clam is not found in the United States. Once established in mains and pipe, it would be harder to remove than the Asiatic clam, as it has a holdfast by which it attaches itself.

One can surmize that pump impeller troubles could result from pumping clams, 31 mm long, 25 mm tall, 15 mm broad, and weighing 3–6 g. The hard, calcium carbonate shell covered with chitin makes the adult clam quite durable. If shells of dead clams, especially from the small, immature clams with fragile shells, become fragmented, abrasion of pumps can result. One instance of such abrasion in piston-type sludge pumps by shells of a small type of mollusk has been pointed out (*7*).

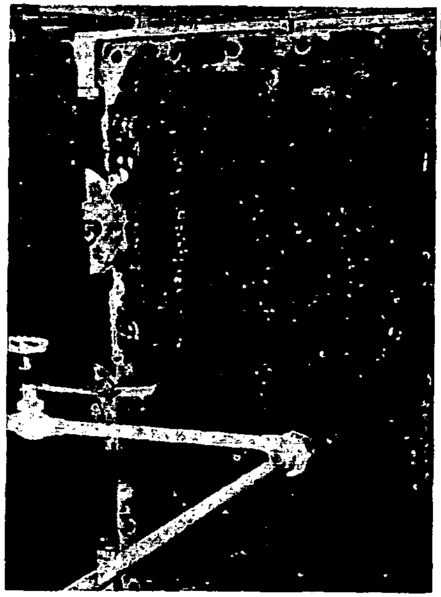

Fig. 2. Clam Infestation of Condenser–Cooler Unit

Lodging of clams such as is shown here has presented a great problem at Tracy Pumping Station, Sacramento, Calif.

Some experimental work, using jar tests to determine the molluscacidal action of copper sulfate and chlorine were carried out by Streicher. It was determined that the combined molluscacidal action of chlorine and copper sulfate was more effective than either alone.

Tracy Pumping Plant

Correspondence in March 1958, forwarded by B. P. Bellport, regional director of Region 2 of the Bureau of Reclamation in Sacramento, Calif., vividly described troubles caused by Asiatic clams at the bureau's Tracy Pumping Station. The material was assembled by H. W. Thomson, chief of the Tracy operations field branch. The main strainers at the pumping station have sometimes required hourly cleaning, owing to the presence of clams. Clams also plug the tubes of the synchronous condenser–cooler units.

The main-line strainers have ¼-in. openings and the heat exchanger tubes are ⅝ in. in diameter. Small clams pass through the strainers, and lodge in the system ahead of the cooler units (Fig. 2), where they increase in size. They are later dislodged, but some are too large to pass through the heat exchanger tubes (Fig. 3).

Molluscacides

A search in 1952 for a molluscacide for clam control indicated that copper sulfate was effective at a 750-ppm concentration with an exposure time of 48 hr. Chlorine was found to give a quicker kill, but the required concentration was corrosive to metal.* In 1953, 2,500 ppm of a relatively inexpensive aromatic solvent was found

* It should also be pointed out that use of copper salts in high dosage will also corrode iron structures.

to be effective and stated to be safe. The present control method is to inject approximately 2,500 ppm of coal-tar naphtha plus an emulsifier into one of the 600-gpm pumps supplying water to the condenser–cooler units until the effluent becomes discolored. The water is then shut off for 24 hr, after which time the unit is flushed at increased velocity using two 600-gpm pumps. The cooler unit heads are then removed and the plugged tubes are cleaned. With this treatment and with use of both pumps in normal operation, the clam control problem in the condenser cooler system has been reduced. Chemical treatment is done in September or October when the condensers can be shut down, but these months are not necessarily the best time of year for effective clam control.

Fig. 3. Clams Removed From Condenser Cooler Unit at Tracy Pumping Station

Clams such as these are too large to pass through the heat exchanger tubes of the cooler and thus lodge and clog the unit (Fig. 2).

Further, it is reported by the Bureau of Reclamation that, after use of copper sulfate for algal control in the Contra Costa Canal, clams and snails contribute to taste and odors in water; also, that clams are undesirable inhabitants in the Delta-Mendota Canal, where they form deposits in the quiescent water of the canal curves, in turnout recesses, and in irrigation boxes.

Habitat and Life Cycle

Corbicula fluminea apparently does well in substrates of sand, or mud, or a combination of the two. A 1958 report (*4*) indicates that in rivers in the vicinity of Taipei, Taiwan, this species prefers a sandy bottom to a silty one. It also appears to prefer a fresh-water habitat. Some species prefer marine habitats, and others show preference for brackish water.

Individual clams bury themselves in the substrate with the posterior end of the shell extending upward into the water to expose the siphons. Microorganisms are drawn into the mantle cavity through the incurrent siphon and eventually enter the mouth where they pass into the digestive system. Solid wastes are extruded from the anal opening and pass out into the water through the excurrent siphon.

The literature is in disagreement on whether Corbicula clams are hermaphroditic or dioecious (*4, 9*). Fertilized eggs develop and hatch in the adult clam. Free-swimming, microscopic larvae are released into the water. A few thousand may be released by a single clam.

Correspondence received from L. O. Weeks of the Coachella Valley County Water District includes data collected by the California Department of Fish and Game relative to clam larvae and states: "Invisible, free-swimming larvae may be in such numbers as to count out 400 per cubic inch of irrigation water." These would be small enough to pass through standard strainers of water meters. Thus, if growth conditions are favorable, the larvae can develop into juvenile or adult clams at almost any point in an irrigation or potable-water supply system. The author has no data that indicate the exact duration of the spawning season for *Corbicula fluminea* on the West Coast. In Taiwan, June through September appears to be the period when spawning occurs and eggs are most numerous (*4*). The duration of the larval stage is not known.

When C. E. Warren, of Oregon State College, studied *Corbicula fluminea* in the Tuolumne River, Modesto, Calif., in 1952–53 he wrote that he had found individual clams of about 1 mm in diameter in considerable numbers from April through October. Such small-sized individual clams distributed over this period indicates a long period of spawning. He observed that a 50-mm length was close to the maximum size reached by this species in the Tuolumne River and hypothesized, from the number of dark shell bands, that clams may reach this length during their seventh summer. The shell erosion noted on 50-mm clams may limit the age to which this species can attain. The largest shells reported from Canton by Prashad were 83 mm long, 77 mm high and 50 mm thick (*8*).

Elimination of Mollusks

Even though chemical treatment may result in successful kills, physical measures must be employed to eliminate Asiatic clam from channels and pipe. The vulnerable link in the life cycle of this clam is the free-swimming larval stage when the young are protected by no shell, or by a poorly developed one, at best, into which the body cannot be withdrawn. Thus, if the spawning seasons for this clam are determined, chemical control measures can be most effectively directed at the naked larvae. As spawning may be triggered by changes in temperature, this period in central California may vary from that in the Coachella Valley, and both of these times vary from Oregon and Washington spawning.

Jar tests on both larvae and adults can determine molluscacidal efficiencies in relation to the strength of compounds and contact time necessary for complete kills. Where drinking-water supplies may be involved, chlorine and certain copper compounds, such as copper sulfate, are the only chemicals recommended by current water treatment practice that could be put to use as molluscacides. The recommended limitation on the use of the latter is delineated by USPHS (*5*) which states that in treated waters copper as Cu should not exceed 3 ppm.

At present too little is known about the toxicities of the newer molluscacides, such as sodium pentachlorophenate (*6*), to think of using them for prophylactic treatment or eradication of mollusks in finished water. Complete information is not at hand to indicate what the toxicity of this compound and others would be to crops or animals that are watered by irrigation supplies.

With the threat of the extension of the Asiatic clam in present and future water development projects, it certainly behooves the administrators of such projects to obtain accurate data on the effectiveness of available molluscacides on larvae and adults. Of greater importance is the simultaneous determination of the presence or lack of toxicity to humans, domestic animals, fish, and plants that would be intimately contacted by irrigation waters.

Nomenclature and Foreign Distribution

Prashad (*8*), who has extensively studied the various species of clams of the genus *Corbicula*, states that *Corbicula fluminea* has a wide range in southeastern China and Korea, and is also found in the Ussuri Basin in southeastern Russia. He lists (*8*) 53 different citations for this species. Some other generic names that have been used in addition to *Corbicula* are *Tellina, Cyrena*, and *Cyclas*.

Uses of Asiatic Clams

Asiatic clams are reportedly used as fish bait in the regions where they occur in Central California. Some specimens now in the US National Museum were taken from the stomach of a sturgeon that was caught in the Columbia River near Bonneville Dam in 1950. In Asia and in the Pacific Islands Asiatic clams are used as food for human consumption. In streams in the vicinity of the municipality of Taipei, Taiwan, as many as 200 fishing boats, mostly on the Tanshui River, may be seen trawling for them (*4*). It has been estimated that over 300 families of the Taipei municipality make their livings in this way. A good day's clam fishing for a one-man boat may result in a catch of about 100 lb. Large and medium-sized clams are sold alive; clam meats are also dried for sale. Small-sized clams are used for feeding ducks. In addition, on the Keelung River in the vicinity of the municipality of Taipei, ducks, themselves, forage for clams.

Data indicate (*4*) that the annual worth of *Corbicula* clams to the Taipei fishery is several million Taiwan dollars. It is not clear (*4*) as to whether *Corbicula fluminea* is the sole species marketed, or whether the estimates are also based on *Corbicula formosana*, which is also found in abundance in the Tanshui River in the vicinity of Taipei, and which apparently prefers brackish water.

Acknowledgments

The author wishes to express his appreciation for the assistance and supporting interest of the following persons: Russell Hart and R. F. Poston, USPHS; B. P. Bellport and H. W. Thomson, Bureau of Reclamation; H. Gilbert Crecelius, Arizona State Department of Health; G. Dallas Hanna and Leo George Herlein, California Academy of Sciences; Harald Rehder and J. P. E. Morrison, US National Museum; Lee Streicher, Metropolitan Water District of Southern California; Charles E. Warren, Oregon State College; Lowell O. Weeks and C. S. Hale, Coachella Valley County (Calif.) Water District.

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Water Yield and Reservoir Storage in the United States

In a five-page report, recently published by the US Geological Survey as Circular 409, Walter B. Langbein discusses the amount of water now made available by reservoir storage and considers the prospects for increasing that amount to meet estimated future needs. According to the report, the aggregate capacity of regulatory reservoirs in the United States (exclusive of those of less than 5,000 acre-ft capacity) increased from 33,000,000 acre-ft in 1920 to 273,000,000 acre-ft in 1953, and the trend in construction is still upward. The computed annual water supply made available by present reservoirs is 190,000,000 acre-ft. This amount, reduced by an estimated net evaporation loss of 10,000,000 acre-ft (mostly in the western states), is 13 per cent of the total flow of the nation's rivers.

Water control through storage is governed by the law of diminishing returns; each successive increment of control requires more storage space than the preceding increment. Storage capacity equal to a year's flow can regulate 40 per cent of the flow, but doubling the capacity only increases regulation by about a third. Thus, although a considerable increase in usable supply could be obtained through additional storage in the East, some drainage basins in the western states may already be approaching a limit. In the Colorado River, for example, an increase in the present storage capacity of 29,000,000 acre-ft to a proposed 50,000,000 acre-ft would probably be largely offset by increased evaporation losses.

It has been estimated that an annual increment of 10,000,000 acre-ft of storage will be necessary to meet anticipated increases in water use. At that rate increased demand will approximately double the amount of necessary storage in the next 25–30 years. The biggest challenge offered by the prospect of increasing demand is that of providing storage where it will be most effective. Estimates have shown that proper placement of storage could mean the difference between a necessary capacity of approximately twice the present capacity and more than four times that amount.

Zone of Aeration and Its Relationship to Ground Water Recharge

Irwin Remson, James R. Randolph, and Henry C. Barksdale

A contribution to the Journal by Irwin Remson, Geologist, James R. Randolph, Geologist, and Henry C. Barksdale, Hydr. Engr., all of Ground Water Branch, USGS, Trenton, N.J.

CERTAIN phases of the relationship of the zone of aeration to the water table, climatic factors, and ground water recharge have been studied at Seabrook, N.J. The description in this article of the occurrence of water in the zone of aeration at Seabrook is based largely upon tensiometer readings.

Recharge

Water percolating into relatively dry sediments at Seabrook must wet each layer of the aeration zone approximately to field capacity before moisture drainage to the layer below can take place at a substantial rate. The depth to which a given rainfall or irrigation application, or both, penetrate depends largely upon the thickness and previous moisture content of the top layer of the aeration zone. The rate at which the water penetrates depends upon the amount of water and the nature of the sediments. If insufficient water is applied to the surface to wet the unsaturated zone to field capacity the percolating water stabilizes at some level above the water table and then dissipates by much slower downward drainage and by vapor transfer.

Ground water recharge generally occurs by the infiltration and downward percolation of precipitation or stream flow through the zone of aeration to the water table. Hydrologic conditions in the zone of aeration are critically important in ground water recharge and are not completely understood. This article will describe studies of movement of water in the zone of aeration made by USGS at two especially favorable sites at Seabrook, N.J. One site is in a forest clearing where the water table is approximately 17 ft below the land surface; the other is in an open, grassy area where the water table is approximately 13 ft below the land surface. The sediments at these sites are predominantly sandy.

The description given in this article is applicable for the soil and climatic conditions at Seabrook and should not be assumed to apply elsewhere without further study. However, it is believed that the results of the study confirm Meinzer's threefold division of the zone of aeration (*1, 2*) described later in this article.

Suction and Field Capacity

Suction, or soil-moisture tension, is a measure of the attraction of the soil for water at any given point. Suction generally decreases as the moisture content of the soil increases. As stated