5.0 DISCUSSION

5.1 Impingement and Entrainment

The total number of species collected during each study at the HL&P generating stations varied a great deal. The largest number of taxa collected were found at the Cedar Bayou station [168, (SRI unpublished data)]. However, Jobe et al. (1980) only collected 65 taxa during their study at the Cedar Bayou station. Moderate numbers of species were collected at the Robinson station [89 Landry (1977), 84 (Chase 1978), and 81 (Greene et al. 1980a)], the Bertron station [86 (Greene et al. 1979)], and the Webster station [76 (Greene et al. 1980b)]. The fewest number of species were collected at the Deepwater station [19 (Greene 1980].

It is difficult to compare results from all HL&P plants due to variations in: (1) the year sampling was conducted; (2) sampling effort; (3) sampling gear; (4) plant specifications (e.g., approach velocity, pump capacity, and number of screens sampled per intake structure); and (5) location of each generating station. Other factors affecting the number of organisms and species impinged include species life history, distribution patterns, and swimming capability; age, health, and previous injuries of individual organisms impinged; and water quality and habitat suitability at intakes for each facility. In addition, changes in hydrological parameters from year to year can result in population fluctuations. These population fluctuations, in turn, can affect the number the number of organisms impinged from year to year. However, as previously mentioned, only two impingement studies at HL&P facilities cover multi-year periods. On a more local scale, concentration of organisms at each intake could also affect the number of organisms impinged. A discussion of some of those factors for which information was available from the studies reviewed follows.

5.1.1 <u>Factors Affecting Species Richness and Abundance of Organisms</u>

Landry's (1977) study was one of the earliest conducted: February 1969 through March 1970. However, Chase (1978) (June 1974 through November 1974 and May 1975 through September 1975), and Chase (1977) and McAden (1977) (June 1974 through September 1975), were conducted during the same period of time. The period of study for Jobe et al. (1980) and Greene et al. (1979, 1980a, 1980b), and Greene (1980) were very similar in that they occurred during calendar years 1978 and 1979. Finally, the SRI data for the Cedar Bayou station (April 1973 to December 1980) was the only data set, besides Greene (1980) at the Deepwater station, that extended data gathering over a multi-year period.

Sampling efforts varied at the HL&P facilities studied. For example, at the Robinson station (Greene et al. 1980a), sampling effort per intake structure 780 minutes (26 collections/year x 30 min./collection). Each intake at the Robinson plant contained six screens. Total sampling time per year at the Webster station (Greene et al. 1980b) was also 780 minutes (26 collections/year x 30 min./collection). The intake structure at the Webster plant consisted of two intakes for Units 1 and 2, and three units at Unit 3. Total sampling time per year at the Bertron station (Greene et al. 1979) was 780 minutes (26 collections x 30 min./collection). There were two intake structures at the Bertron plant consisting of four intake bays at each intake structure. Total sampling time per year at the Deepwater station (Greene 1980) was 120 minutes (12 collections x 10 hr/collection). The intake structure at the Deepwater plant consisted of 3 intake bays. For the Cedar Bayou station (SRI unpublished), the number of collections per year ranged from 84 in 1980 to 271 in 1977. Samples were collected quarterly and biweekly, depending on the year. In addition, the duration of sample collections was 240 minutes/collection for quarterly samples and 80 minutes/collection for biweekly samples. In summary, sampling effort varied from 80 minutes/collection for biweekly samples at the Cedar Bayou station to 780 minutes/collection at the Robinson (for intakes A and B individually), Webster, and Bertron stations. Also, the number of screens sampled per intake varied which would indicate that the cross-sectional area of water column sampled could vary at each facility.

Another factor affecting both species richness and total abundance of organisms may by the velocity at the intake screens. Landry (1977) found that small or weak-swimming larvae, postlarvae, and young fish were susceptible to impingement and entrainment when intake approach velocities averaged over 1.1 fps. With all units in operation, the maximum intake approach velocity corrected for subsidence at the Deepwater station was 0.76 fps (Table 4.15). The fewest number of species were collected at the Deepwater station. Calculated approach velocities at the Robinson, Webster, and Bertron stations were all greater than 1 fps, with most greater than 1.38 fps at maximum low water (Tables 4.2, 4.11, and 4.13). Seventy six (76) or more species were collected at each of these stations. One hundred sixty eight (168) taxa (the most at any station) were collected at the Cedar Bayou station during the 8-year period when SRI was collecting data for HL&P. However, the calculated approach velocities at the this facility ranged between 0.783 fps to 0.920 fps, some of the lowest approach velocities at the HL&P generating stations. Therefore, other factors may be more important with respect to the number of species collected at each facility.

Pump capacity varied among the various HL&P generating stations. Total pumping capacities were the highest at the Robinson (4 units, 1,167,000 gpm) and Cedar Bayou (3 units, 1,042,000 gpm) stations. Species richness were among the highest at these stations (89 species at Robinson and 168 taxa at Cedar Bayou). Total pump capacity at the Bertron station was 514,000 gpm (4 Units), 391,000 gpm at the Webster station (3 units), and 305,000 gpm (7 units) at the Deepwater station. The number of species impinged at these three stations was highest at the Bertron station (86 species), followed by the Webster station (76 species), and the Deepwater station (19 species).

With respect to location, Robinson, Webster, Deepwater, Bertron, and Cedar Bayou generation stations are all located in different parts of Galveston Bay (Figure 2). Differences in life history and distribution patterns, and quality and availability of habitat of each species may account for differences in the species diversity and richness at each location.

Perhaps the most obvious factor that may have resulted in fewer species being collected at the Deepwater station would be water quality. Bechtel (1970) found that upper Galveston Bay had serious water quality problems. He found that the number of fish species occurring in that area was reduced and the average size of fish was smaller than those occurring in lower portions of the bay. Bechtel (1970) also stated that species diversity increased as one moved down the Houston Ship Channel from Morgan's Point to Bolivar Roads. This improvement was consistent with the long-held premise that as distance from a source of pollution or stress increases, there is a corresponding increase in species diversity. This might explain the increase in species between the Bertron station as compared to the Deepwater station.

In addition, Seiler et al. (1991) reported that early studies of the upper Houston Ship Channel indicated little use of the area by nekton. This was supported by Chambers (1960) who found the area upstream of the confluence with the San Jacinto River devoid of nekton. By the mid-1970s, diversity and utilization of TWC Segment 1006 (San Jacinto River to Greens Bayou) by nekton had greatly improved; however, TWC Segment 1007 (Greens Bayou to the Turning Basin) remained depauperate (TDWR 1980). The studies by Chambers (1960) and the TDWR (1980) probably reflected conditions present during the Greene (1980) study of the HL&P Deepwater station. However, Seiler et al. (1991) showed an increase in use by nekton of the Houston Ship Channel as evidenced by the collection of 46 species from intake screens at the HL&P Deepwater station (i.e., Segment 1007) and 45 species from intake screens at the Occidental Chemical Plant in Deer Park (i.e., Segment 1006). Seiler et al. (1991) stated that the results of their study indicated that the upper portions of the Houston Ship Channel is an important habitat for juvenile fish and macroinvertebrates. They suggested that the increase in use by nekton of the upper portions of the Houston Ship Channel could be attributed to the considerable improvement in water quality resulting from increased state and federal regulations and more restrictive effluent requirements. Despite improvements in water quality, dissolved oxygen levels are occasionally below segment criteria of 2.0 mg/L for Segment 1006 and 1.0 mg/L for Segment 1007. In addition, total and orthophosphorus concentrations for both segments are persistently elevated, and inorganic nitrogen concentrations are frequently elevated in Segment 1006 and regularly elevated in Segment 1007 (TWC 1990).

The species most frequently impinged and entrained at all HL&P generating stations were white shrimp, blue crab, Gulf menhaden, bay anchovy, sand seatrout, spot, and Atlantic croaker (Table 4.3). Species less frequently impinged or entrained were brown shrimp, sea catfish, and striped mullet. Brown shrimp were collected in abundance at all HL&P generating stations except the Deepwater station (Figure 2). Sea catfish were collected in abundance only at the Robinson and Webster stations. Striped mullet were collected in larger numbers at the Robinson, Bertron, and Webster stations.

Using plankton nets with smaller mesh sizes, Chase (1977) identified six larval fish as the most abundant during her study of entrained zooplankton at the Robinson plant. These included the naked goby, juvenile Gulf menhaden, bay anchovy, and larval comb-tooth blennies. These results were supported by Greene et al. (1980b) who reported the most abundant finfish species in 153 um-mesh net samples collected from the Webster station as bay anchovy, naked goby, Gulf menhaden, and Atlantic croaker.

Other species affected by impingement and entrainment, albeit to a much lesser degree, were commercially and recreationally important species such as spotted seatrout, black drum, red drum, and southern flounder. Generally, commercially or recreationally important finfish were not impinged in large numbers with respect to the most abundant species. However, both spotted seatrout and southern flounder were included with the species comprising one percent or more of impingement at the Robinson (Greene et al. 1980a) and Webster (Greene et al. 1980b) stations. At the Robinson station, both spotted seatrout and southern flounder were included because they comprised 1.2 percent and 1.03 percent of impingement, respectively, by weight and not by number. At the Webster station, spotted seatrout and southern flounder comprised 1.2 percent and 1.5 percent by weight, respectively. Neither species comprised one percent or more of impingement by number.

5.1.2 Length - Frequency and Seasonal Distribution

Brown Shrimp

Brown shrimp were collected at all HL&P stations for which impingement data were collected (Table 4.3). Brown shrimp were generally collected from mid- to late May through June at all stations. A second peak of abundance was noted at the Robinson station from September through November. The size range for brown shrimp impinged was 10 mm to 170 mm. However, most brown shrimp impinged ranged from 44 mm to 122 mm. No length-frequency information was provided in the SRI data from Cedar Bayou.

White Shrimp

White shrimp were collected at all HL&P stations for which data were available. Peak abundance periods were July through September, and November through December. The size range of white shrimp collected was 30 mm to 158 mm. Most white shrimp collected ranged from 49 mm to 158 mm at the Robinson station, 58 mm to 94 mm at the Webster station, and the mean size at the Cedar Bayou station (Jobe et al. 1980) was 85 mm. White shrimp at the Deepwater station were somewhat smaller, ranging from 30 to 60 mm. No length-frequency information was provided in the SRI data from Cedar Bayou.

Blue Crab

Blue crabs were present throughout the year at most stations. In studying the effects of entrainment, McAden (1977) collected blue crabs ranging in size from 2.4 mm to 10.0 mm with a 12.5-cm Clarke-Bumpus sampler. With respect to impingement, at the Robinson and Bertron stations, blue crabs were present throughout the year with no discernible trends in abundance. However, peak period of impingement at the Deepwater station were January through March and November through December for both years, and November at the Webster station. The peak periods of impingement at the Cedar Bayou station was May to September. With respect to length, the size range of blue crabs impinged was 5 mm to 210 mm. Most blue crabs at all stations fell within this range. However, the range at the Deepwater station was somewhat smaller, 10 mm to 65 mm. The mean size range within which most crabs were impinged was 24 mm to 124 mm. The mean size impinged at the Cedar Bayou station was 87 mm (Jobe et al. 1980). No length-frequency information was provided in the SRI data from Cedar Bayou.

Gulf Menhaden

The peak period of impingement and entrainment of Gulf menhaden varied from station to station. Gulf menhaden were impinged at all HL&P stations. Landry (1977) reported that peak periods of entrainment at the Robinson station coincided with peak recruitment periods of March and April, and January through March. He also reported that peak periods of impingement were February through June when water temperatures were the coolest and the abundance of juveniles was at its peak. Peak periods of impingement varied from September and December through March at the Robinson station (Greene et al. 1980a), the first of November through mid-December at the Bertron station (Greene et al. 1979), December through February and April through November at the Webster station (Greene et al. 1980b), and November through April with a peak in March at the Cedar Bayou station (SRI unpublished).

Landry (1977) reported that Gulf menhaden less than 30 mm were susceptible to entrainment, and that those organisms less than 20 mm were susceptible to entrainment upon entry into the intake canal. In considering all HL&P stations, the size range of Gulf menhaden impinged ranged from 5 mm SL to 900 mm SL. The smallest size at which menhaden were most often impinged ranged from 15 mm SL at the Webster station to 45 mm SL at the Robinson station. The largest size at which menhaden were most often impinged ranged from 75 mm SL at the Robinson station to 105 mm SL at the Bertron station.

Bay Anchovy

Bay anchovies were impinged or entrained in large numbers at all locations. With respect to entrainment, bay anchovies were collected from May through July and September through October at the Robinson station (McAden 1977). Landry (1977) reported a similar peak entrainment period of May through September. The peak impingement period at Cedar Bayou was April (SRI unpublished). The size range of entrained anchovies was 10 mm SL to 38 mm SL in McAden's study. Landry (1977) reported that anchovies less than 20 mm SL were entrained upon entering the intake canal, and that entrainment was enhanced for organisms between 20 mm SL to 50 mm SL with increased proximity to the intake structure.

The size ranges of impinged anchovies ranged from 20 mm SL to 65 mm SL at the Robinson station (Landry 1977) to 40 mm SL to 70 mm SL and 20 mm SL to 30 mm SL at the Deepwater station (Greene 1980). The lengths impinged at Cedar Bayou ranged from 15 mm to 90 mm (SRI unpublished) Landry (1977) reported that the anchovies most frequently impinged ranged in size from 50 mm SL to 70 mm SL.

Sand Seatrout

Sand seatrout were collected from revolving screens or discharge canals at all HL&P facilities studied (Table 4.3). Landry (1977) concluded that the effect of entrainment on this species was minimal since very few were collected in the discharge canal at the Robinson station. However, the sand seatrout collected ranged in size from 9.7 mm SL to 76.5 mm SL in ichthyoplankton nets, and from 13 mm SL to 303 mm SL in trawls. Sand seatrout caught in ichthyoplankton nets were usually less than 30 mm SL. The greatest number of seatrout in the discharge canal was collected in June.

Peak periods of impingement for sand seatrout varied from May to August (Landry 1977) and no apparent trend (Greene et al. 1980a) at the Robinson station, to September and November at the Webster station, to November through January at the Bertron station (Greene et al. 1979), to November or December at the Deepwater station (Greene 1980), to May through July at the Cedar Bayou station (SRI unpublished).

The overall size ranges of sand seatrout impinged varied among the HL&P stations studied. The smallest sizes impinged ranged from 5 mm SL at the Robinson (Greene et al. 1980a) and Bertron (Greene et al. 1979) stations to 20 mm SL at the Deepwater (Greene 1980) and Cedar Bayou (SRI unpublished) stations. The longest seatrout impinged ranged from 60 mm SL at the Deepwater station (Greene 1980) to 315 mm SL at the Robinson station (Greene et al. 1980a). The most frequently impinged sand seatrout ranged from a minimum size of 27 mm SL to 51 mm SL to a maximum size of 65 mm SL to 148 mm SL.

Spot

Spot were collected from all HL&P stations sampled (Table 4.3). The only peak period for entrainment reported was March for the Robinson station (Landry 1977). Spot collected in ichthyoplankton nets ranged from 4.7 mm SL to 57 mm SL. Spot collected in trawls ranged from 25 mm SL to 115 mm SL. Most spot entrained were less than 30 mm SL (Landry 1977).

With respect to impingement, Landry (1977) reported that spot collected from intake screens at the Robinson station ranged from 28 mm SL to 142 mm SL. The size range for spot most frequently impinged ranged from 30 mm SL to 65 mm SL. The peak period of abundance at the Robinson station was February through April. The only other study reporting length-frequency data was Jobe et al. (1980) for Cedar Bayou. The average size of spot impinged was 43 mm SL with a range of 20 mm SL to 120 mm SL.

Atlantic Croaker

Atlantic croaker were collected at all HL&P stations. Landry (1977) reported that the Atlantic croaker captured with ichthyoplankton nets in the Robinson discharge canal ranged in size from 3.4 mm SL to 82.4 mm SL. Croaker collected by trawl in the discharge canal ranged in length from 12 mm SL to 157 mm SL. Atlantic croaker most susceptible to entrainment were less than 30 mm SL. Croaker were most frequently entrained from January through April.

The smallest length of Atlantic croaker impinged ranged from 5 mm SL (Robinson and Bertron stations) to 50 mm SL (Deepwater station). The largest croaker impinged ranged from 60 mm SL (Deepwater station) to 315 mm SL (Robinson station). The smallest length of croaker most frequently impinged ranged from 27 mm SL (Robinson station) to 51 mm SL (Bertron station). The longest croaker most frequently impinged ranged from 65 mm SL (Robinson) to 148 mm SL (Webster station). The peak period of abundance ranged from mid- to late winter through mid- to late spring. At the Cedar Bayou station, most croaker were impinged from February through June with a peak in March (SRI unpublished).

Sea Catfish

Sea catfish were collected only at the Robinson and Webster stations (Table 4.3). Sea catfish collected in the discharge canal at the Robinson station ranged from 98 mm SL to 147 mm SL in trawls; none were collected in ichthyoplankton nets. Landry (1977) reported that young-of-the-year catfish were liberated at 35 mm SL to 40 mm SL, and were susceptible to entrainment until they reached a length of 50 mm SL. The peak periods of entrainment were April and September.

At the Robinson station, sea catfish were impinged at lengths ranging from 42 mm SL to 248 mm SL. The length of catfish most frequently impinged ranged from 50 mm SL to 80 mm SL during the late summer.

Striped Mullet

Striped mullet were impinged at the Robinson, Bertron, Webster and Cedar Bayou stations. However, length-frequency data and peak impingement periods were reported only for Cedar Bayou. The peak impingement period at Cedar Bayou was March through July. Lengths of impinged mullet ranged from 20 mm to 390 mm (SRI unpublished).

Spotted Seatrout

Spotted seatrout comprised less than one percent of all organisms captured at all HL&P stations except the Deepwater station where none were collected. At the Robinson station, spotted seatrout were collected in the discharge canal at lengths ranging from 3.8 mm SL to 11.2 mm SL in ichthyoplankton nets and 57 mm SL to 173 mm SL in trawls. Peak periods of abundance were July through September (Landry 1977).

The lower limit of spotted seatrout impinged ranged from 30 mm SL (Cedar Bayou station) to 65 mm SL (Bertron station). The upper limit ranged from 173 mm SL (Robinson - Landry 1977) to 470 mm SL (Robinson - Greene et al. 1980a). The mean size range of spotted seatrout most frequently impinged ranged from 70 mm SL (Webster station) to 198 mm SL (Bertron station). This species was most frequently impinged from fall through winter at the Robinson station (Landry 1977) to November through March at the Bertron station (Greene et al. 1979).

Red Drum

Red drum comprised less than one percent of all organisms collected at all HL&P stations for which data were collected except the Deepwater station where none were collected. Entrained red drum ranged from 6.0 mm SL to 8.5 mm SL in the discharge canal at the Robinson station (Landry 1977). The period of most frequent entrainment was April through July.

Impinged red drum ranged from a minimum length of 35 mm SL (Robinson -Greene et al. 1980a) to 41 mm SL (Robinson - Landry 1977) to a maximum length ranging from 94 mm SL (Robinson - Landry 1977) to 380 mm SL (Bertron). The peak period of impingement ranged from early to mid-winter through late winter to early spring.

Black Drum

Black drum comprised less than one percent of all organisms collected at all HL&P stations for which data were collected except the Deepwater station where none were collected. Twenty black drum were impinged during Landry's (1977) study at the Robinson station. They ranged in length from 40 mm SL to 283 mm SL with most being impinged at lengths ranging from 40 mm SL to 84 mm SL. Most black drum were impinged in June.

Black drum (101) were also impinged at the Webster station (Greene et al. 1980b). They ranged from 25 mm SL to 260 mm SL with mean sizes ranging from 42.5 mm SL to 58.0 mm SL. Most black drum were impinged during January. At the Cedar Bayou station, of the 186 black drum collected most were impinged in September. Their lengths ranged from 40 mm to 285 mm (SRI unpublished).

Southern Flounder

Southern flounder comprised less than one percent of all organisms collected at all HL&P stations, except the Deepwater station where none were collected. Landry (1977) reported that only one southern flounder was entrained at the Robinson station. However, 77 were impinged on intake screens. These fish ranged from 29 mm SL to 272 mm SL. No periods of peak abundance were noted.

Greene et al. (1980a) reported that southern flounder impinged at the Robinson station ranged in length from 10 mm SL to 375 mm SL. At the Webster station, impinged flounder ranged from 70 mm SL to 375 mm SL with most fish most frequently caught ranging in length from 94 mm SL to 248 mm SL (Greene et al. 1980b). No periods of peak abundance were noted at either the Robinson or Webster stations. The flounder most frequently impinged at the Bertron station ranged from 49 mm SL to 192 mm SL with most being impinged from mid-April to the first of June (Greene et al. 1979). Southern flounder impinged at Cedar Bayou ranged from 20 mm to 340 mm. The peak impingement period was May through June with secondary peaks in November through December and February (SRI unpublished).

5.1.3 Survival in Cooling Water Operations

Of all the literature reviewed, only Landry (1977), Chase (1978), Chase (1977), and Jobe et al. (1980) discussed injury rates or survival of organisms in cooling water operations. Landry (1977) described injury rates immediately after impingement and entrainment, and briefly discussed temperature tolerances of finfish within the Robinson station discharge canal. Chase (1978) addressed survival rates for organisms impinged during both intermittent and continuous operation of intake screens at the Robinson station. He also evaluated the delayed effects of impingement by placing organisms collected from intake screens operated on a continuous basis in cages in the intake canal. These organisms were observed until they died or up to five to eight days, whichever was longer. He also calculated probabilities of overall survival based on the results of his short- and long-term survival studies. He did not address the effects of elevated temperature on test organisms. Chase (1977) studied the immediate survival of entrained zooplankton and fish eggs and larvae at the Robinson station. She discussed the relationship between short-term survival and passage through cooling towers and the discharge canal. Jobe et al. (1980) evaluated both the short- and long-term survival of impinged organisms at the Cedar Bayou station. They studied survival immediately after impingement, after impingement and passage through a fish pump, and up to 96-hour after impingement, passage through the fish pump, and placement in the heated discharge canal.

Landry (1977) found that the susceptibility of most species to cooling-water operations was dependent upon their life history, swimming ability, water temperature, and current. Most young fish entered the intake canal at the Robinson station in a series of well-defined recruitment waves, particularly when water temperatures dropped during the fall and winter. Impingement rates were, therefore, greater during this time. Small or weak-swimming larvae, postlarvae, and young fish were susceptible to impingement and entrainment when intake approach velocities averaged over 1.1 ft/sec.

Fish were attracted to the intake canal by the stronger currents. Some fish were observed feeding in front of intake screens and, therefore, may have moved into the intake bays for feeding purposes (Chase 1978). Some prey species may have been chased into screens while other species may have become exhausted from swimming into the current and drifting back into the screens. Most of the fish impinged during the study were young or juveniles.

Highest injury rates attributed to impingement and entrainment occurred during the summer months when fewest fish were present. Spot and Atlantic croaker were the only species that established well-defined resident populations in the discharge canal. However, these populations were driven from the canal when temperatures exceeded 32C. In addition, summertime temperatures exceeding 35C were very stressful to organisms in the discharge canal as evidenced by the lack of numbers captured at the far end of the canal.

5.1.3.1 Injury Rates

Landry (1977) used the following criteria to classify fish as injured: (1) presence of puncture wounds; (2) hemorrhaging around eyes, mouth parts, and fins; (3) scale abrasions; (4) deformation of body parts; (5) rupture of coelomic cavity; (6) absence of body parts; and (7) decaying of fish flesh and body parts. Injury rates for impinged fish and entrained fish (i.e., those collected in discharge canal by ichthyoplankton nets or trawls) appear in Table 4.4. Landry (1977) did not study the long-term effects of impingement or entrainment on fish survival.

For the most abundant species at the Robinson station, injury rates by number for impinged fish ranged from 2.6 percent for Atlantic croaker to 34.2 percent for bay anchovy. Injury rates for entrained fish were generally lower than those for impinged fish of the same species. However, sample sizes for entrained fish were much lower than those for impinged fish. Injury rates for entrained fish ranged from no injured sea catfish to 15 percent for bay anchovy (Table 4.4). Bay anchovy was the most abundant species impinged and entrained and had the highest injury rates.

Recreationally important species such as spotted seatrout, red drum, black drum, and southern flounder were impinged or entrained in very small numbers. Of 27 post-larval spotted seatrout either impinged or entrained, none were injured. None of the red drum collected were visibly injured. Of the 21 black drum collected, the overall injury rate for this species was 4.8 percent. Southern flounder had the highest injury rates for these four species: 11.7 percent of 27 individuals.

5.1.3.2 Immediate and Delayed Effects of Impingement

Chase (1978) went one step farther than Landry (1977) in determining the impacts of cooling water operations. Landry (1971 and 1977) reported only injury rates. Chase (1978), on the other hand, reported immediate percent survival as well as the delayed effects of impingement. His criteria for death were lack of body movement and no indication of respiration. Chase's study emphasized sampling during the time cooling towers were in operation (i.e., June to November 1974 and May to September 1975) which coincided with the presence of more species in the area.

In most cases, for both intermittent and continuous operating procedures, survival was greater at Units 1 and 2 than at Units 3 and 4. The only exceptions were for blue crab (immediate effects of impingement, continuous operation), sand seatrout (immediate effects of impingement, intermittent operations), Atlantic croaker (immediate effects of impingement, both intermittent and continuous operations), Atlantic cutlassfish (immediate effects of impingement, intermittent operations) (Table 4.7), white shrimp, and sea catfish (delayed effects of impingement) (Table 4.8). With the exception of these species, these conclusions generally hold true for the empirical probabilities of survival (Table 4.9) which include both the immediate survival rates and the delayed effects survival rates.

Generally speaking, Chase (1978) found that survival rates were greater during continuous operation of the intake screens as opposed to intermittent operation. The only exceptions were for blue crab at Units 3 and 4 (Table 4.7). However, he concluded that when the empirical survival probabilities were applied to proportionate catches at respective stations (i.e., fewer organisms were collected at Units 1 and 2 but survival rates were higher at these stations while more organisms were caught at Units 3 and 4 but survival was lower) the results demonstrated that continuous screen operation did not substantially increase survival rates.

The majority of organisms were collected from Units 3 and 4 as compared to Units 1 and 2. Chase (1978) gave two reasons for the higher number of organisms caught and the lower survival at Units 3 and 4 versus Units 1 and 2. He stated that screen-related injury is often cited as a function of approach velocity and the volume of water pumped into the plant (Clark and Brownell 1973). Calculated approach velocities at maximum low water for all four units were very similar (Table 4.2). However, calculated approach velocities at mean low water were greater for Units 3 and 4. In addition, the pumping capacity at Units 3 and 4 was also much greater than at Units 1 and 2 (Table 4.2).

Another factor causing higher injury rates to already impinged fish was the presence of the colonial hydroid (*Bimeria franciscana*). Hydroid mats and large numbers of ctenophores on the screens may have resulted in asphyxiation of impinged organisms (Chase 1978). Crabs caused additional injuries by preying on impinged organisms (Chase 1978, Landry 1971).

Immediate and delayed survival rates for crustaceans (shrimp and crabs) (Tables 4.7 and 4.8) were much greater than for fish for intermittent and continuous operation of the screens at the Robinson station. The immediate and delayed survival rates for crustaceans were generally greater than 70 percent. Overall probabilities of survival were also much higher for crustaceans than fish (Table 4.9).

The Atlantic cutlassfish was the species most sensitive to the immediate effects of impingement. The other most abundant fish (i.e., Gulf menhaden, sea catfish, sand seatrout, spot, Atlantic croaker, and Atlantic spadefish) were less sensitive than the Atlantic cutlassfish and equally sensitive as a group. Gulf menhaden, Atlantic cutlassfish, bay anchovy, and Atlantic bumper were also very sensitive to the delayed effects of impingement. Overall probabilities of survival for the most abundant fish were generally less than 0.10, with spot and Atlantic spadefish having some of the larger probabilities of survival.

Chase's (1978) probabilities did not include the effects of elevated temperatures in the discharge canal. Test organisms that were impinged or entrained were placed in cages in the intake canal where they were subjected to ambient temperatures and not elevated temperatures from the power plant. Therefore, these probabilities may be indicative of survival rates in the discharge canal when thermal tolerance of entrained organisms were not exceeded, perhaps September through April. Also, only organisms collected during continuous operation of the screens were used in the cage study. Chase (1978) stated that estimates of the delayed effects of impingement may be conservative because more injury and probably greater delayed mortality occurred as a result of intermittent screen operations than from continuous screen operations. Therefore, JN concluded it would only be appropriate to apply Chase's (1978) probabilities to other power plants where screen operations, intake velocities and pumping rates are comparable.

Jobe et al. (1980) studied the effects of impingement, passage through a fish pump, and long-term (i.e., 96 hours) survival in the Cedar Bayou station discharge canal. Survival rates immediately after impingement at the Cedar Bayou station were much greater than those reported by Chase (1978) at the Robinson station. Crustaceans, again, had the highest immediate survival rates (>95%). Most of the abundant fish had survival rates greater than 70 percent with many such as Gulf menhaden, spot, and southern flounder greater than 90 percent. The most sensitive species was the least puffer with an immediate survival rate of 44 percent (Table 4.19).

Survival rates immediately after impingement and passage through the fish pump were generally greater than 70 percent with for all species with crustaceans (i.e., white shrimp, brown shrimp, and blue crab) among the highest (>84%). The most sensitive species were red drum (0%) and black drum (50%), but these results were suspect because the sample sizes were very small. Of the six species tested for long-term effects of impingement and passage through the fish pump, sand seatrout was the most sensitive with 13 percent survival. The remaining species tested (i.e., spot, Atlantic croaker, blue crab, white shrimp, and brown shrimp) had survival rates greater than 50 percent. Again, crustaceans were hardier than fish (Table 4.19).

Only six species were used in the heat-shock studies. No sand seatrout survived. Spot, white shrimp, and brown shrimp survival rates ranged between 19 percent to 27 percent. Atlantic croaker survival rates were 40 percent, while blue crab was the hardiest species tested with a 66 percent survival rate. Overall, survival rates for all species decreased from impingement to passage through the fish pump to placement in the discharge canal.

5.1.3.3 Effects of Heat

According to Landry's (1977) observations, Gulf menhaden appeared to be one of most sensitive species to elevated temperatures. He stated that juvenile menhaden probably did not survive in the discharge canal after entrainment when temperatures were greater than or equal to 30 C.

Chase (1977) found juvenile menhaden in the Robinson station discharge canal from December 1974 through March 1975 when water temperatures ranged from 20.0 C to 23.4 C. The percentage of menhaden caught alive in this temperature interval ranged from 92.3 percent to 100 percent.

Landry (1977) found the next most sensitive species to be Atlantic croaker with temperatures greater than 32 C repelling them from the discharge canal. Atlantic croaker survival was variable in the Jobe et al. (1980) heat shock studies. There was 0 percent survival at temperatures greater than 29 C and at 19.4 C and 21.8 C. However, there was 50 percent survival at 18.5 C and 78 percent survival at 24.2 C.

Other species such as bay anchovy, sea catfish, sand seatrout, and spot avoided temperatures greater than 35 C (Table 4.6). Chase (1977) reported that 0 percent of juvenile bay anchovy survived when temperatures ranged from 36.1 C to 40 C. She also reported that no live bay anchovies were reported in the vicinity of the Robinson station cooling towers from May to July 1975 when water temperatures ranged from 32.2 C to 37.8 C at the cooling tower intakes, from 30.0 C to 33.9 C inside cooling towers, and from 32.2 C t 36.7 C downstream from the cooling towers. Sand seatrout did not survive at any temperatures (18.5 C to 41.1 C) in heat shock studies (Jobe et al. 1980) probably indicating that they were extremely sensitive to the overall effects of cooling water operations. Spot were also sensitive to elevated temperatures as there was 0 percent survival when discharge water temperatures exceeded 29.2 C. There was 57 percent survival at 18.5 C (Jobe et al. 1980).

Small numbers of larvae from the family Blenniidae were collected by Chase (1977) in the Robinson station discharge canal when water temperatures ranged from 21.1 C to 32.7 C. Survival at these temperatures was 100 percent. Survival decreased to 64.3 percent when water temperatures increased to 36.7 C. No individuals were found after that with water temperatures ranging as high as 38.4 C.

Survival in the Robinson station discharge canal for larvae from the family Gobiidae was generally low during July and August 1974 and May through August 1975 when water temperatures exceeded 36 C. With few exceptions, all larval gobies were dead when collected at all cooling tower stations (Chase 1977).

Chase (1977) reported that passage through condensers did not cause substantial mortality to brown shrimp at ambient temperatures of 27.8 C to 29.5 C and discharge temperatures of 35.6 C to 38.9 C. Wiesepape (1975) found that brown and white shrimp can increase their thermal resistance by first acclimatizing to higher salinities. In a 96-hour heat shock studies after impingement and passage through a fish pump, Jobe et al. (1980) found that percent survival for blue crab ranged from 47 percent to 100 percent at discharge temperatures ranging from 18.5 C to 32.3 C. Survival decreased to 31 percent when the discharge water temperature was 33.3 C. Blue crab had 0 percent survival when temperatures in the discharge canal were greater than 36 C. In the same study, brown shrimp survival was 0 percent when discharge canal water temperatures were equal to and greater than 33.3 C. Percent survival ranged from 33 percent to 69 percent at temperatures ranging from 18.5 C to 32.3 C. No white shrimp survived when temperatures exceeded 33.3 C. Percent survival decreased from 76 percent at 18.5 C to 0 percent to 58 percent when temperatures ranged from 29.2 C to 32.3 C.

Fish egg survival in the Robinson station discharge canal ranged from 11.3 percent to 54.3 percent during June through August 1975 when discharge canal water temperatures ranged from 38.4 C to 38.9 C. However, there was 100 percent survival in May and September 1975 when temperatures were 35.6 C (Chase 1977). In contrast, no fish eggs were found alive in the cooling towers from July to September 1975 when water temperatures in the cooling tower ranged from 32.2 C to 34.7 C. Chase (1977) suggested that repeated bouncing on splash fill in cooling towers damaged the delicate eggs.

While temperature tolerances for many species were exceeded in the Robinson station discharge canal during the warmer months (i.e., May through August), there were beneficial effects in the cooler months. Landry (1977) found that the sizeable abundance and rapid growth of young-of-the-year spot during March and April 1969 were indicative of favorable water temperatures (16.5 C to 31 C) during late winter and spring.

5.1.4 Annual Impingement Estimates

Projected annual numbers and weights for organisms impinged at Robinson (Greene et al. 1980a), Webster (Greene et al. 1980b), Bertron (Greene et al. 1979), and Deepwater (Greene 1980) stations were calculated by HL&P for the years studied. The HL&P projections for those species comprising 1% or more of the total number impinged and additional commercially and recreationally important species appear in Table 4.5. JN calculated annual estimates for the number and weight of 16 taxa impinged at the Cedar Bayou station using the SRI data collected during the period of study (Table 23). These 16 represent over 93% of the total number of organisms impinged at Cedar Bayou (i.e., those organisms (12 species) comprising 1% or more of the total number impinged 4 additional commercially and recreationally important species).

There was one year, 1978, when impingement data were collected at all five HL&P stations evaluated in this report. The 1978 annual projections and/or estimates calculated by HL&P and JN appear below:

Station	**1978 Annual Projections/Estimates**	
	Number	**Weight (kg)**
Cedar Bayou	54,665,326	243,025
Robinson	17,556,118	121,724
Bertron	8,590,106	59,297
Webster	6,252,239	53,304
Deepwater	16,717	104
TOTAL	**87,080,506**	**477,454**

For 1978, the total number and weight of organisms estimated impinged at the Cedar Bayou station were greater than numbers and weights projected impinged for all other HL&P facilities combined. Because of the lack of multiyear data at the Robinson, Webster, Bertron, and Deepwater facilities, one cannot determine if this rank order listing of stations would remain constant. However, both the total number and total weight of the most frequently, and commerically and recreationally important organisms impinged at the Cedar Bayou station show a decreasing trend from 1975 to 1980 (Appendix L).

As discussed in Section 5.1.3.2, not all organisms impinged or entrained are killed. In addition, survival rates were greater from September through April when impinged organisms sluiced to discharge canals would not be exposed to temperatures which exceeded their thermal tolerances. Lower survival rates would occur during May through August when discharge canal water temperatures exceeded thermal tolerances. Also, the data reviewed indicated that fewer organisms were impinged during summer months. Finally, survival studies showed that crustaceans (white shrimp, brown shrimp, and blue crab) generally had higher survival rates than finfish in HL&P cooling water operations. According to the results in Table 4.5, more crustaceans were impinged by number and weight than finfish other than Gulf menhaden. Therefore, the total annual estimated numbers impinged for each species appearing in Table 4.5 overestimate the mortality attributable to impingement and entrainment.

Another factor that would cause these estimates of the number and weight of species impinged to be low is that they do not include impingement at other facilities withdrawing water from Galveston Bay. The results of the JN survey of permitted water rights users within Galveston Bay indicated that the Sterling Chemical facility was the only other major water rights user on Galveston Bay. Because of its location and plant specifications (i.e., intake velocity and pumping capacity), it is possible that the Sterling Chemical facility could impinge the same order of magnitude of number, weight, and variety of organisms as the Robinson station.

5.1.5 Impacts to Fisheries Population Dynamics

One of the objectives of this study was to address any implications of non-fishing human induced mortality patterns as they affect fisheries population dynamics. According to TPWD Coastal Fisheries staff, there is no sure way to assess the standing crop of fish populations in Galveston Bay with any degree of certainty. However, relative abundance is assumed to be a good indicator of the standing crop status. Also, the study by Loeffler and Walton (1992) can be used to evaluate the status of fisheries populations in Galveston Bay.

It is difficult to determine what impact impingement and entrainment had on fisheries population dynamics in Galveston Bay. The study by Loeffler and Walton (1992) discussed CPUE trends from 1963 to 1968 (NMFS data) and 1975 to 1990 (TPWD data). The impingement results from HL&P facilities were reported in number and weight impinged usually over a one-year period, except at the Deepwater (1978 and 1979) and Cedar Bayou (1973 to 1980) stations.

At any rate, Loeffler and Walton (1992) reported that, of the 14 species analyzed, only blue crab and white shrimp showed chronic declining trends in CPUE. For blue crab, there was a strong decreasing trend reported for juveniles (50 mm to 70 mm), first-time spawners (120 mm to 140 mm), and other adult crabs (>140 mm). These size classes fall into the overall size range of blue crabs impinged at HL&P facilities (5 mm to 210 mm), and the juveniles and first-time spawners fall into the mean size range most frequently impinged at HL&P facilities (24 mm to 124 mm). Approximately 56% of blue crabs estimated impinged at HL&P facilities during 1978 to 1979 (Table 4.5) were from the Cedar Bayou station (SRI unpublished). While no size ranges were reported in the SRI data, JN was unable to determine any obvious trend in the number of blue crabs impinged during the 8-year study period (see Section 4.2.4.2).

With respect to white shrimp, Loeffler and Walton (1992) reported that juveniles (80 mm to 100 mm) and first-time spawners (110 mm to 130 mm) were the only size classes for which decreasing trends were observed. The sizes of white shrimp impinged at HL&P facilities ranged from 30 mm to 158 mm. The most frequently impinged size ranges at HL&P facilities were 49 mm to 158 mm (Robinson), 58 mm to 94 mm (Webster), a mean of 85 mm (Cedar Bayou, Jobe et al. 1980), and 30 mm to 60 mm (Deepwater). Therefore, the most critical life stages of young of the year and first-time spawners, were more often impinged at the Robinson and Deepwater stations. Approximately 55% of white shrimp estimated impinged at HL&P facilities during 1978 to 1979 (Table 4.5) were from the Cedar Bayou station (SRI unpublished). While no size ranges were reported in the SRI data, a decreasing trend was observed in the number of white shrimp impinged from 1975 to the end of the study in 1980 (see Section 4.2.4.2).

5.2 Fish Kill Records

The results of study of fish kills in coastal waters of the U.S. from 1980 to 1989 by the National Oceanic and Atmospheric Administration (NOAA) (Lowe et al. 1991) revealed that more fish were reported killed (159 million) in Texas than any of the 21 other states reporting results. In addition, more dead fish (106 million) were reported killed in Galveston County than any other county in the states studied. Galveston and Chambers counties were among the counties reporting the greatest concentration of major fish kills (i.e., one million or more fish) with eight and five, respectively. The largest reported fish kill in the study occurred in Galveston County (Jolly Rogers Canal, Jamaica Beach) where an estimated 50 million Gulf menhaden were killed. The cause was attributed to low dissolved oxygen from unspecified sources. This specific fish kill was not evaluated in this JN report because it was not identified as human-induced. However, both the JN and NOAA studies evaluated reports from the TWC and TPWD. A discussion of the results of JN's review of Texas fish kill records follows.

No cause could be identified for approximately 89 percent of the 175.2 million fish reported killed. Deaths related to nonpoint sources were attributed to 9.3 percent of the total and the remaining 1.4 percent were associated with point source incidents. Unknown sources also caused the majority of incidents (55 percent of the total), while NPS and PS caused 20 percent and 25 percent, respectively. The available data were evaluated under these main source categories since each have varying potential for controls. Point sources are much more controllable than nonpoint sources since a definable area can be determined for which preventative measures can be implemented. Nonpoint sources caused the highest amount of fish mortality but are much more difficult to control. These are usually associated with large areas in which many contributory causes may exist, and may or may not be associated with human activity. Point sources enter waterways at discrete, identifiable locations and can usually be monitored directly, while nonpoint sources are regional in nature. Point sources are controllable at a specific site while NPS is best controlled through land management techniques such as conservation practices in rural zones, and architectural controls in urban zones.

5.2.1 Point Source Mortality

The available fish mortality data for point source incidents were characterized by 2,377,303 fish killed in 56 incidents. Ninety six percent (96%) the fish killed due to point sources were associated with only seven of the 29 identified sources and only 23 percent of the total number of incidents. These sources were: unknown spills at power generation facilities, an ocean dumping accident, STP plant by-passes, pipe leaks at chemical manufacturing facilities, unknown activities at chemical manufacturing facilities, and detonation of explosives from undefined activities. No chronic patterns were found for point sources since the number of events were fairly evenly distributed among the 29 categories. Only three source categories were found involving more than three incidents reported over a 20-year period of record. These were heated water discharges from power generation plants, STP plant by-passes, and unknown activities at miscellaneous industries.

The primary pollutants associated with point sources attributed to fish mortality were manufactured chemicals, industrial wastewater, sewage, and shockwaves induced by explosives at construction sites. Chemical spills and industrial wastewater discharges caused a combined 69 percent of the point source related fish mortality. Less than two percent were affected by food industry wastes, heated water discharges, and oil spills. The most frequently reported PS incidents involved heated water discharges (12 events) and chemical spills (15 events). Other point source pollutant categories were involved in two to seven incidents each.

Approximately 90 percent of the total fish mortality occurred in five of the 42 segments in which fish kills were reported. These were tributaries to Clear Lake (x2425), San Jacinto Bay (2427), West Bay (2424), Clear Creek (1101), and tributaries to West Bay (x2424). Twenty nine percent (29%) of the total number of reported PS incidents occurred in these five segments. The largest number of different types of point source categories affected tributaries to Clear Lake, tributaries to Lower Galveston Bay, and tributaries to West Bay. Four source categories were identified as affecting tributaries to Clear Lake. These were pipe leaks at chemical manufacturing facilities, fish processing waste discharges, leaks from holding pits, and undefined activity at miscellaneous industries. Tributaries to Lower Galveston Bay were affected by pipe leaks at chemical manufacturing facilities, elevated pollutants in permitted discharges at chemical manufacturing facilities, mishandling spills during barge operations, and unknown activity at miscellaneous industries. Tributaries to West Galveston Bay were affected by a trucking accident spill, illegal waste disposal, and unknown activity at miscellaneous industries. No other segments were impacted by more than two source categories.

Size distribution data for point source related incidents were most representative of seismic testing operations in West Galveston Bay and thermal discharges from power generation facilities located on Cedar Bayou and Upper Galveston Bay. Of 244,118 fish for which length information were available, 99 percent were associated with seismic testing operations in West Galveston Bay, less than two percent were associated with thermal discharges at power generation facilities, and the remainder were in association with seven additional PS categories.

A seismic testing operation conducted in West Bay killed a total of 241,800 fish. The relatively large amount of fish length information available for this source was due to extensive efforts used to recover dead fish during blasting operations. Results indicated that the most affected fish were one to two-inch bay anchovies (30 percent of the total), five-inch pinfish (25%), and five to six-inch spot (23%). Thirty percent (30%) of the fish affected by the blasts were rough fish species, 13 percent were commercial varieties, and 70 percent were either sport or commercial fish (some overlap occurs between sport and commercial fish). Other species killed included silver perch, Atlantic croaker, striped mullet, black drum, and sheepshead.

Between January 1986 and March 1992, the GLO issued 74 geophysical permits in Galveston Bay (Mr. Micky Rumsey, GLO, personal communication). Over the last 10 years, only dynamite (up to 20 lbs) and air guns have been permitted as energy sources. GLO regulations require that dynamite has to buried 120 feet below the bay bottom. The company conducting geophysical operations that killed an estimated 241,800 fish in West Bay was using 40 pounds of dynamite buried 120 feet deep. Apparently, the depth of natural gas deposits for which they were exploring required more pounds of dynamite than usually permitted by GLO. Based on the JN literature review and contacts with state agencies, no studies of geophysical exploration using 20 pounds of dynamite have been conducted. Therefore, it is not known whether this fish kill occurred because 40 pounds of dynamite were used or whether fish kills occur with the 20 pounds of dynamite permitted by GLO. However, in the 20 year period of record, only one seismic related fish kill has been reported in Galveston Bay.

In addition to this TPWD study, there have been various studies that document the effects of seismic sources on fish in Texas (Kemp 1956, Linton et al. 1985, Spears 1980). Linton et al. (1985) reported that fish with swim bladders are susceptible to damage from high-velocity explosive detonations (e.g., dynamite, Petrogel, high explosive charges, nitramon, Nitro-Carbo-Nitrate, Nitrone, SM, NCN, Geogel, and primacord). High velocity explosives produce a pressure wave of very large pounds per square inch. The rapid rise and fall of pressure causes fish swim bladders to rupture because they cannot compensate for the rapid change in internal pressure. Organisms without swim bladders such as shrimp, crabs, and oysters are less likely than fish to be injured by seismic sources. The GLO does require that warning shots be fired before the detonation to frighten fish from away from the testing site. However, Burner and Moore (1963) found that warning shots are ineffective because fish become quickly accustomed to sound in water and ignore them. In fact, fish are attracted to an area from a previous seismic explosion in search of dead fish as a food source.

The GLO requires that dynamite be buried 120 feet below the bay bottom during geophysical exploration. Rasmussen (1967) found that burying charges at increasing depths lead to a general reduction in the lethal effect. Maximum mortality was observed when charges (5.5 pounds of dynamite) were buried less than 30 feet and little or no mortality when burial depths greater than 30 feet were used.

Heated water discharged from power generation facilities killed a reported 10,679 fish of which length data were available for 2,026. Of twelve species included in these data, the most affected were four-inch Gulf menhaden (20 percent of the total), six-inch Atlantic croaker (18%), and 17-inch gizzard shad (18%). Othr species were the hardhead catfish, seepshead, Gulf toadfish, striped mullet, southern flounder, sand seatrout, spotted seatrout, red drum and black drum. These data were collected for a total of three incidents occurring at the Robinson power plant on Upper Galveston Bay and one at the HL&P Cedar Bayou generating station.

The remaining fish length data included 635 individuals affected by seven separate source categories other than seismic testing and thermal discharges. These were sewer line leaks (58 percent of the total), a barge liquid transfer spill involving vinyl acetate (16.5%), and a sewage leak from a storage tank (15.7%). The remaining 10 percent were caused by explosives detonation at a construction site, pipe leaks of crude oil, a sewage treatment plant by-pass, and a mishandling spill from an unidentified industry.

Data associated with seismic testing is not representative of seasonal fluctuations since it was based on information collected during a short time interval in the fall which does not account for seasonal migration patterns. Length data associated with mortalities caused by heated water discharges occurred during the summer months.

Essentially all of the fish mortality caused by point sources occurred during May to October with peaks developing in May and September. The numbers of reported incidents were shown to climax in May and gradually decrease until February. Fish mortality due to point sources were found to be less influenced by seasonal patterns than nonpoint sources.

5.2.2 Nonpoint Source Mortality

A total of 16.3 million fish was reported killed from nonpoint sources. Unclassified rough fish represented 71 percent of the total and were found in 58 percent of the recorded incidents. Gulf menhaden was the most chronically affected species, killed in 11 of the 43 incidents and comprising 29 percent of the total mortality.

A single nonpoint source category was responsible both for the vast majority of fish killed and the number of reported incidents. Ninety three percent (93%) of the mortality was associated with undefined runoff associated with 81 percent of the reported incidents. A single event involving the discharge of anoxic irrigation tailwater accounted for an additional six percent of the total killed by NPS. Less than one percent were attributed to rice field drainage, urban runoff, and runoff from industrial areas. Agricultural runoff affected only two segments; Trinity Bay and tributaries to East Galveston Bay. Urban runoff killed 0.13 percent of the total in four waterbodies: Dickinson Bayou, tributaries to the Intracoastal Waterway, tributaries to West Galveston Bay, and tributaries to Clear Lake. The largest urban runoff incident occurred in Dickinson Bayou killing approximately 20,000 Gulf menhaden. Forty percent (40%) of the segments were affected by runoff from undefined areas killing 93 percent of the fish affected by NPS. The most affected of these were Dickinson Bayou, tributaries to East Bay, San Jacinto Bay, and tributaries to Clear Lake each experiencing over one million fish killed.

Only four pollutant categories were associated with nonpoint source incidents. These were agricultural runoff, oil washoff, urban runoff and runoff associated with undefined areas. The vast majority (93.7%) of the numbers of fish reported killed were affected by undefined NPS. Agricultural runoff accounted for six percent of the total. Undefined NPS occurred in 34 of the 43 reported NPS incidents. Agricultural runoff, oil washoff, and urban runoff were responsible for between two and four NPS incidents each.

Almost ninety two percent (92%) of the fish mortality caused by NPS occurred in only seven segments: Dickinson Bayou (1103), tributaries to East Bay (x2423), San Jacinto Bay (2427), tributaries to Clear Lake (x2425), Cedar Bayou (0901), Trinity Bay (2422), and tributaries to the Trinity River (x0801). These represented 49 percent of the total number of NPS incidents.

Fish length data for mortalities caused by nonpoint sources included 5,760 individuals representing eight species. These were sheepshead minnows, Gulf menhaden, Atlantic croaker, striped bass, red drum, hardhead catfish, southern flounder, and striped mullet. The most affected fish were three-inch Gulf menhaden (40 percent of the total), six and eight-inch striped bass (17%) each, and one-inch sheepshead minnows (13%). Gulf menhaden were killed due to urban runoff, runoff from industrial landfills, and runoff from undefined areas. Striped bass and sheepshead minnows all were affected by runoff from industrial landfills, and all other species were killed due to runoff from undefined areas.

Nonpoint source mortality was most prevalent in June through September with a peak occurring in August, both for numbers killed and numbers of reported incidents. This trend follows the seasonal pattern of weather conditions that are conducive to oxygen depletion during the summer months. Most of the nonpoint source-caused mortalities were attributed to low dissolved oxygen levels caused by increased algal populations induced by nutrient input. The combination of bright sunny days, warm water and rain events which produce runoff from urban, agricultural and industrial areas create an environment in which plankton populations increase. During nighttime algal respiration, photosynthetic oxygen production ceases. Large plankton populations can cause lethal nighttime oxygen sags in shallow waters in which a large fraction of the water column contains plankton. This is enhanced under light wind conditions and when water temperatures are elevated.

5.2.3 Unknown Source Mortality

Unidentified sources accounted for 156,496,069 of the fish reported killed. Unclassified rough fish comprised 95 percent, Gulf menhaden two percent and unclassified game fish one percent of the total. Unclassified rough fish were included in 92 of the 121 incidents associated with unknown sources while Gulf menhaden, striped mullet and red drum were found in four to six incidents each.

Pollutant categories were identified for only ten of the 121 incidents involving unknown sources. These were chemical spills associated with nine incidents in which 216,085 unclassified rough fish were killed, and two incidents involving oil spills (killing one red drum each). The remainder were attributed to low dissolved oxygen levels of unknown origin.

Seventy five percent (75%) of the fish mortality attributed to unknown sources occurred in only five waterbody segments. Thirty nine percent (39%) were killed in the Houston Ship Channel, in which over 99 percent were unclassified rough fish and the remainder unclassified game fish. These data were collected during the time when more specific species identification was not made during field investigations. Eleven percent (11%) were killed in upper Galveston Bay and in the Bayport Channel. Unclassified rough fish comprised 91 percent of the fish killed in upper Galveston Bay and over 99 percent of the Bayport Channel deaths. Nine percent (9%) of the fish killed in this category were found in tributaries to west Galveston Bay. A greater diversity of species were identified here, including Atlantic croaker, Atlantic needlefish, Gulf menhaden, and hardhead catfish. Unclassified rough fish comprised over 99 percent of the total. Dickinson Bayou experienced 7 percent of the total, primarily unclassified rough fish. Others included unclassified catfish, finescale menhaden, Gulf menhaden and red drum. Tributaries to the Houston Ship Channel also tallied 7 percent of the total killed. Unclassified rough fish accounted for 91 percent and Gulf menhaden made up 9 percent.

Unknown source mortality was most prevalent from July through October during which 80 percent of the total were reported killed. Peak mortality occurred in the early fall though the most incidents were recorded in July. This may be due to greater public activity along Galveston Bay waterways during the summer months resulting in a larger percentage of incidents being noticed. A single incident in October 1977 in the Houston Ship Channel between Greens Bayou and the Baytown Tunnel resulted in over 61 million fish deaths due to low dissolved oxygen levels, possibly caused by elevated algal populations.