Appendix S

Description of Marine Mammal and Sea Turtle Species

By Marine Acoustics, Inc.

Affected Environment: Description of Marine Mammal and Sea Turtle Species Occurring Off the West Coast of Hawai'i, Site of the Kona Kai Ola Project

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MAI-642-U-07-053
24 June 2007

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Marine Acoustics Inc. Technical Report

Affected Environment: Description of Marine Mammal and Sea Turtle Species Occurring Off the West Coast of Hawai'i, Site of the Kona Kai Ola Project

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24 June 2007

Introduction

These descriptions are provided for all turtle and marine mammal species that could conceivably occur near the site of the Kona Kai Ola project. While the probability of occurrence of some species is very low, the descriptions are provided for completeness. This section will summarize data on abundance and behavior, which affects how the animal samples the environment (and the sound field produced by Kona Kai Ola). Descriptions of hearing ability (when known) and vocalization range are provided to document the probable sound frequency range and susceptibility to potential acoustic disturbance. Other threats to the species are summarized.

This document was written for inclusion in the Kona Kai Ola Environmental Impact Statement (EIS) as a separate appendix and is intended to provide detailed descriptions of marine mammals and sea turtles that are too large for inclusion in the EIS, but are necessary to support the analyses contained in the EIS.

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1.0 Sea Turtles

Sea Turtle Hearing Capabilities and Sound Production

Data on sea turtle sound production and hearing are few. Therefore these are presented in this summary section rather than as species-specific information in each of the following species descriptions. There is little known about the mechanism of sound detection by turtles, including the pathway by which sound gets to the inner ear and the structure and function of the inner ear of sea turtles (Bartol and Musick 2003). However, assumptions have been made based on research on other species of turtles. Based on the structure of the inner ear, there is some evidence to suggest that marine turtles primarily hear sounds in the low frequency (LF) range and this hypothesis is supported by the limited amount of physiological data on turtle hearing. Bartol and Musick (2003) state that the amount of pressure needed to travel through the bone channel of the ear increases with an increase in frequency. For this reason, it is believed that turtles are insensitive to high frequencies and that they primarily hear in a LF range. A description of the ear and hearing mechanisms can be found in Bartol and Musick (2003). The few studies completed on the auditory capabilities of sea turtles also suggest that they could be capable of hearing LF sounds, particularly as adults. These investigations examined adult green, loggerhead, and Kemp's ridley sea turtles (Ridgway et al. 1969; Mrosovsky 1972; O'Hara and Wilcox 1990; Bartol et al. 1999). There have been no published studies to date of olive ridley, hawksbill, or leatherback sea turtles (Ridgway et al. 1969; O'Hara and Wilcox 1990; Bartol et al. 1999 Bartol and Ketten 2006).

Underwater sound was recorded in one of the major coastal foraging areas for juvenile sea turtles (mostly loggerhead, Kemp's ridley and green sea turtles) in the Peconic Bay Estuary system in Long Island, NY (Samuel et al. 2005). The recording season of the underwater environment coincided with the sea turtle activity season in an inshore area where there is considerable boating and recreational activity, especially during July-September. During this time period, received levels (RLs) at the data collection hydrophone system in the 200-700 Hz band ranged from 83 dB (night) up to 113 dB (weekend day). The sea turtles are undoubtedly exposed to high levels of noise, most of which is anthropogenic. Results suggest that continued exposure to existing high levels of anthropogenic noise in vital sea turtle habitats and any increase in noise could affect sea turtle behavior and ecology (Samuel et al., 2005). However, there were no data collected on any behavioral changes in the sea turtles due to anthropogenic noise or otherwise during this study.

Ridgway et al. (1969) used airborne and direct mechanical stimulation to measure the cochlear response in three juvenile green sea turtles. The study concluded that the maximum sensitivity for one animal was 300 Hz, and for another 400 Hz. At the 400 Hz frequency, the turtle's hearing threshold was about 64 dB in air (re: 20 μPa). At 70 Hz, it was about 70 dB (re: 20 μPa) in air. Sensitivity decreased rapidly in the lower and higher frequencies. From 30 to 80 Hz, the rate of sensitivity declined approximately 35 dB. However, these studies were done in air, up to a maximum of 1 kHz, and thresholds were not meaningful since they only measured responses of the ear; moreover, they were not calibrated in terms of pressure levels.

Bartol et al. (1999) measured the hearing of juvenile loggerhead sea turtles using auditory evoked potentials to LF tone bursts and found the range of hearing to be from at least 250 to 750 Hz. The lowest frequency tested was 250 Hz and the highest was 1000 Hz.

More recently, Streeter and colleagues (pers. comm., 2005) were able to train a female green sea turtle to respond to acoustic signals. The results from this study showed a hearing range of at least 100 to 500 Hz (the maximum frequency that could be used in the study, as opposed to what may be a wider hearing range) with hearing thresholds of 120-130 dB RL. However, there are several important caveats to these results. First, the study was done in a relatively noisy oceanarium. Thus, the thresholds reported may have been masked by the background noise and the "absolute thresholds" (the lowest detectable signal within a noisy environment) may be several dB lower than the reported results. Second, data are for a single animal who is well into middle age (over 50 years old) and who had lived in an oceanarium all its life. While there are no data on effects of age on sea turtle hearing, data for a variety of mammals (including humans) show there is a substantial decrement in hearing with age, and this may have also happened in this animal. This too may have resulted in thresholds being higher than in younger animals (as used by Ridgway et al., 1969). Finally, the data are for one animal and so nothing is known about variability in hearing, or whether the data for this animal are typical of the species.

Most recently, Bartol and Ketten (2006) used auditory evoked potentials to determine the hearing capabilities of subadult green sea turtles and juvenile Kemp's ridleys. Subadult Hawaiian green sea turtles detected frequencies between 100 and 500 Hz, with their most sensitive hearing between 200 and 400 Hz. However, two juvenile green turtles tested in Maryland had a slightly expanded range of hearing when compared to the subadult greens tested in Hawai'i. These juveniles responded to sounds ranging from 100 to 800 Hz, with their most sensitive hearing range from 600 to 700 Hz. The two juvenile Kemp's ridleys had a more restricted range (100 to 500 Hz) with their most sensitive hearing falling between 100 and 200 Hz.

Green Turtle (*Chelonia mydas*):

Green turtles are globally distributed and generally found in tropical and subtropical waters along continental coasts and islands between 30° North and 30° South (NMFS and USFWS 1998a). In the central Pacific, they occur around most tropical islands, including the Hawaiian Islands.

Greens are the most common species of sea turtle found in Hawaiian waters (Balazs 1983). Both the nesters and the turtles resident at various foraging grounds throughout the Hawaiian Archipelago are from the same genetic stock (Leroux et al. 2003), although rarely turtles from the east Pacific stock that nests along the Pacific coast of Mexico are recorded in Hawaiian waters (Balazs, 1976; Dutton, 2003). Green sea turtles in Hawai'i were once seriously depleted, but have demonstrated a substantial long-term increase in abundance following cessation of harvesting since protection began in 1978 (Balazs & Chaloupka 2004; Balazs & Chaloupka 2006). At some locations in Hawai'i prominent changes in the adaptive behavior of the turtles have occurred concomitant with this recovery trend. These include shifts in near shore foraging from night to daytime, exceptional tolerance to humans, emergence ashore for resting or basking, and formation of underwater cleaning stations (Balazs 1996).

Green turtles make the transition from pelagic to benthic habitats at around 5-10 years of age (Dutton 2004). The diets of post-hatchlings and juveniles living in pelagic habitats appear to be entirely carnivorous (e.g., invertebrates and fish eggs), but records are only known from the occasional turtles encountered (for review see Bjorndal 1985). Adult green turtles are unique among sea turtles in that they are herbivorous, feeding primarily on macroalgae and sea grasses (e.g. *Halophila hawaiiatza* in Hawai'i) and spend most of their lives in shallow bays and nearshore areas where these plants are present (Balazs, 1980; Bjorndal, 1985; Balazs et al., 1987).

Foraging behavior of green turtles is well documented and in Hawai'i is typically characterized by numerous short dives (4 to 8 min) in shallow water (typically less than 3 m) with short surface intervals (less than 5 sec) (Balazs, 1980; Rice et al. 1999). Resting periods are characterized by longer dives (over 20 min) in deeper water (4 to 40 m) with surface intervals averaging 2.8 min (Rice et al. 1999). The amount of time that turtles spend foraging versus resting is still largely unknown. Green turtles in Hawai'i frequently use small caves and crevices in the sides of reefs as resting areas, and spend significant amounts of time on the tops of reefs (Balazs et al., 1987).

Green sea turtles in the Atlantic swam faster in open ocean travel (mean = 61 km/day) (2.54 km/h) than along the coast (mean = 25 km/day) (1.05 km/h) (Hays et al. 2002). Green turtles migrating in Hawaiian waters had a mean speed of 1.7 km/h (Balazs and Ellis 2000).

The green turtle is the only marine turtle species reported basking on land. Terrestrial basking in the main Hawaiian Islands has increased dramatically since 1994 (Quaintance et al. 2003). It is believed to be carried out for thermoregulation and also possibly for protection from the tiger shark (*Galeocerdo cuvieri*) a major predator of the green turtle (Balazs et al., 1987). Rice et al. (1999) conducted studies at Punalu'u on the island of Hawai'i and found that basking (averaging 130 min) was typically initiated in the middle of the day, yet continued into the night.

The nesting season for the Hawaiian stock of green turtles is May through July (Balazs and Chaloupka 2004). Nesting occurs throughout the Hawaiian archipelago, but over 90% occurs at French Frigate Shoals, Northwestern Hawaiian Islands (NWHI), where 200-700 females are estimated to nest annually (NMFS and USFWS 1998a). Adult turtles migrate to French Frigate Shoals from foraging pastures up to 1300 km away (Balazs 1994) located throughout the Hawaiian Archipelago (Balazs 1976, 1983b) and Johnston Atoll, immediately to the South, where algal foraging pastures occur (Balazs 1985a).

Primary threats to green sea turtles in Hawai'i include nest predation, directed take, fisheries incidental take, boat collisions and disease. Recent increases in longline fisheries may be a serious source of mortality. Greens comprised 14% of the annual observed take of all species of turtles by the Hawai'i-based longline fishery from 1990 to 1994 (NMFS and USFWS 1998a). Over the period of 1994 to 1999, it was estimated that

an annual average of 40 green sea turtles were caught in the Hawai'i-based longline fishery (McCracken 2000).

Recent proliferation of a tumorous disease known as fibropapillomatosis (Balazs et al. 1992; Balazs and Pooley 1991) threatens to eliminate improvements in the status of the Hawaiian stock (NMFS and USFWS 1998a). The disease is characterized by grayish tumors of various sizes, particularly in the axial regions of the flippers and around the eyes. This debilitating condition can be fatal and neither a cause nor a cure has been identified.

The green turtle is listed as "threatened" under the Endangered Species Act (ESA) throughout its Pacific Range, except for breeding populations in Florida and on the Pacific coast of Mexico, which are classified as "endangered". It is listed as "endangered" worldwide by the International Union for the Conservation of Nature and Natural Resources (IUCN), and the species appears on Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (CITES 2005).

Hawksbill Turtle (*Eretmochelys imbricata*):

Hawksbill turtles are globally distributed in tropical and subtropical waters, generally occurring from 30° North to 30° South within the Atlantic, Pacific, and Indian Oceans and associated bodies of water (NMFS and USFWS 1998b). Hawksbills were once common in the nearshore waters from Mexico to Ecuador. Today, however, they are rare to nonexistent in most localities and are virtually unknown along coastal waters of the U.S. Pacific (NMFS and USFWS 1998b). In the Hawaiian Islands their range is limited to the main islands where they are present in relatively few numbers (Balazs 1983). About 20-30 female hawksbills nest annually in the Main Hawaiian Islands (NMFS and USFWS 1998b). In 20 years of netting and hand-capturing turtles at numerous nearshore sites in Hawai'i, only eight hawksbills (all immatures) have been encountered at capture sites including Kiholo Bay and Ka'u (Hawai'i), Palo'ou (Moloka'i) and Makaha (O'ahu) (NMFS and USFWS 1998b).

Hawksbills are primarily near-shore reef dwellers. They make the transition from pelagic to benthic habitats at around 5 years of age (Dutton 2004). It was only recently discovered that hawksbills appear to be specialist sponge carnivores (Meylan 1988). Hawksbills forage in coral reefs and other hard-bottom habitats in open bays and coastal zones throughout the tropics and, to a lesser extent, the subtropics, including Florida, the Gulf of Mexico, the USVI, Puerto Rico, Hawai'i, and the U.S. Pacific territories (Plotkin 1995).

Juvenile hawksbills in coral reef habitats display an alternating pattern of short, shallow (less than 5 m) foraging dives followed by deeper (6- to 9-m), longer resting dives (Houghton et al. 2003; Van Dam and Diez 1996). Two tagged female hawksbill in Hawai'i had dive times of about 50 minutes and showed an prolonged residency pattern in the Hamakua region (Balazs et al. 2000). Hawksbills are known to migrate along the coast of the islands and between islands (e.g. Hawai'i and Maui) (Ellis et al. 2000).

Within the Central Pacific, nesting is widely distributed but scattered and in very low numbers. In Hawai'i, about 20 to 30 female hawksbills nest annually, only on main island beaches (NMFS and USFWS 1998b), between July and November (Plotkin 1995), primarily along the east coast of the island of Hawai'i. Beaches on Hawai'i with recorded hawksbill nesting include Kamehame, Punalu'u, Horseshoe, Ninole, Kawa Pohue and within Hawai'i Volcanoes National Park (NMFS and USFWS 1998b).

Hawksbills appear to be rarely caught in pelagic fisheries (McCracken, 2000). Incidental catches of hawksbill turtles in Hawai'i occur, primarily in nearshore gillnets (NMFS and USFWS 1998b). The primary threats to Hawksbills in Hawai'i are increased human presence, beach erosion and nest predation (e.g., by mongooses) (NMFS and USFWS 1998b). Illegal harvest for local consumption is also reported from Hawai'i where an unquantified number of hawksbills are taken for domestic black markets (NMFS 1992).

The hawksbill is threatened with extinction throughout its range (NMFS and USFWS 1998b). Hawksbill turtles are listed as "critically endangered" under the IUCN, "endangered" throughout their range under the ESA, and is included in Appendix I of CITES (CITES 2005). With the exception of the Kemp's ridley, the hawksbill is considered by many to be the most endangered of all the marine turtles (Plotkin 1995).

Leatherback turtle (*Dermochelys coriacea*)

Leatherback turtles are the most migratory and wide ranging of sea turtle species. They are distributed widely between 71° North and 42° South in the Pacific and all other major oceans and tend to be almost entirely pelagic (Dutton 2004). They are highly migratory, exploiting convergence zones and upwelling areas in the open ocean, along continental margins, and in archipelagic waters (Dutton 2004). Leatherbacks regularly occur in the offshore waters of the State of Hawai'i where they are sighted by fishermen and sometimes become entangled in fishing gear; these animals may represent individuals in transit from one part of the Pacific to another (Balazs 1983).

They feed primarily on cnidarians and tunicates (Plotkin 1995; NMFS and USFWS 1998c), mostly in deeper waters, but have also been observed at the surface (Eisenberg and Frazier 1983). Leatherback turtles tend to dive, often to great depths, in a cycle that follows the daily rising and sinking of the dense layer of plankton and jellyfish on which they feed (Eckert et al. 1989b). The deepest dive recorded was to 1,230m (4,035 ft), but they usually dive to depths around 250m (820 ft) (Hays et al. 2004). Long distance (> 100 km) intra-seasonal movement sometimes occurs among nesting beaches; for example, between French Guiana and Surinam (Pritchard 1973) and between St. Croix and Puerto Rico (Eckert et al. 1989a).

Female leatherbacks had sustained swim speeds of 0.56-0.84 m/s (2.0-3.0 km/h), with maximum speeds of 1.9-2.8 m/s (6.8-10.0 km/h) (Eckert 2002). Mean dive depths were 93.0 m (SD= 72.8), with dive times of 3.4 minutes (SD = 7.9) and mean surface times were 3.4 minutes (SD = 1.9) (Eckert 2002). The maximum dive depth was 490 m, and on average, dives were deeper during the day than at night (111.6 v 73.0 m).

Leatherback nesting in the Pacific is widespread in the western Pacific, including China, Indonesia, Southeast Asia, and Australia (NMFS and USFWS 1998c). However, there are no known nesting grounds in the Pacific under US jurisdiction. Leatherbacks undertake some of the longest migrations of all sea turtles and can travel great distances between feeding and nesting areas (Dutton 2004). Genetic results, coupled with tag-recapture and satellite telemetry data suggest that the nesting stocks in the western Pacific primarily use the North Pacific for development and foraging, while animals from eastern Pacific stocks generally forage in the Southern Hemisphere, including the waters off Peru and Chile (Dutton, Broderick and Fitzsimmons, 2002). However, there are exceptions to this pattern, since animals of western Pacific stock origin have been found off Chile (Donoso et al., 2000), and likewise, some leatherbacks of eastern Pacific stock origin have been found in the north Pacific (Dutton, Broderick and Fitzsimmons, 2002).

Primary threats to the species are incidental take in coastal and high seas fisheries, and the killing of nesting females and collecting of eggs at the nesting beaches (NMFS and USFWS 1998c). Thirty two percent of the turtles reported captured by the Hawai'i-based longline fisheries during the 1990 to 1994 observer program were leatherbacks (NMFS and USFWS 1998c). Over the period of 1994 to 1999, it was estimated that an annual average of 112 leatherbacks were caught in this fishery (McCracken 2000)

The leatherback turtle is listed as "endangered" under the ESA throughout its global range. It is listed in Appendix I of CITES (CITES 2005) and the Red List 2000 of the IUCN has classified the leatherback as "critically endangered".

Loggerhead Turtle (*Caretta caretta*):

Loggerheads are circumglobal, occurring throughout the temperate and tropical regions, primarily from 28° to 40° North (Polovina et al. 2004). In the Pacific Ocean, loggerhead habitats include ocean and island areas around Polynesia, Micronesia, Melanesia, Indonesia, the Philippines, Australia, China, Japan, Mexico, and the United States (NMFS and USFWS, 1998d). Historically, loggerheads may have inhabited Hawaiian waters. Today juveniles are rarely seen in the Hawaiian Islands, generally north of 22°N. Only four records exist. All four specimens were juveniles and most likely drifted or traveled to Hawai'i from Mexico to the east or Japan to the west (NMFS and USFWS, 1998d). Therefore the likelihood of loggerheads near Honokohau is very low.

Adult loggerheads typically prey on benthic invertebrates (such as gastropods, mollusks, as well as decapod crustaceans) in hard bottom habitats, although fish and plants are occasionally taken (NMFS and USFWS, 1998d). Foraging has also been reported at sea, far from coastal hard bottom habitats (NMFS and USFWS, 1998d). Dive depth distribution data collected from satellite-linked dive recorders attached to two loggerhead sea turtles caught and released in the Hawai'i-based longline fishery, indicated that they spend 40% of their time at the surface and 90% of their time at depths less than 40 m (Polovina et al. 2004). According to Bolten (2003), oceanic loggerheads spend 75 percent of their time in the top 5 m (16.4 ft) of the water column and 80 percent of their dives are within 2 to 5 m (6.6 to 16.4 ft). The maximum depth recorded during a dive was 233 m (764 ft). Mean dive lengths for Loggerhead turtles have been measured at 16.1 min (SD = 6.0) with a range of 5-40 minutes (Lutcavage and Lutz 1991). Oceanic turtles studied in the Azores swam at speeds of 0.2 m/s (0.7 ft/s) (Bolten, 2003). Loggerheads in the Mediterranean Sea typically dove to about 25 m, and had resting (overwintering) dives as long as 10.2 hours, the longest for any vertebrate (Broderick et al. 2007).

Major nesting grounds of the loggerhead are generally located in warm temperate and subtropical regions, with some scattered nesting in the tropics (NMFS and USFWS, 1991b). In the Pacific, loggerhead sea turtles nest in warm temperate and subtropical regions, primarily in Japan and Australia (NMFS and USFWS, 1998d). Loggerheads in Japan are known to migrate across the Pacific to California, carried by the California Current (Luschi et al., 2003). There is no loggerhead nesting in Hawai'i (Balazs 1983) and there are very few records on any of the many islands of the Central Pacific where this species is considered rare or vagrant (NMFS and USFWS, 1998d).

The primary threat to loggerhead populations is incidental capture by commercial trawlers and longline fisheries. Loggerheads comprised 36% of the annual observed take of all species of turtle by the Hawai'i-based longline fishery between 1990 and 1994 (NMFS and USFWS, 1998d). Between 1994 and 1999, 147 loggerheads were observed taken by the Hawai'i-based longline fishery, with a mortality rate of 17.5% (McCracken 2000). The predicted annual take of loggerheads by this fishery is 305 turtles (NMFS and USFWS, 1998d). Results to date in this fishery confirm the reduction in incidental catches of loggerheads that can be achieved from the elimination of shallow sets. Beginning in April 2001, shallow sets were prohibited in the Hawai'i-based longline fishery. Data from the onboard observers in the longline fleet, which now comprise 20% of the fishing effort, showed that no loggerheads were caught from April through December 2001 (Polovina et al. 2003). Coastal development is also a serious threat to loggerhead nesting (NMFS and USFWS, 1991b).

Loggerhead turtles are listed as "threatened" under the ESA, are protected under CITES (CITES 2005) and are listed as "vulnerable" under the IUCN.

Olive ridley turtle (*Lepidochelys olivacea*):

Olive Ridleys occur worldwide in tropical and warm temperate ocean waters. In the Pacific they have been documented from 8° to 31° North (Polovina et al. 2004). It is by far the most abundant and widespread sea turtle in the waters of the eastern Pacific (NMFS and USFWS 1998e). Olive ridleys resident in Pacific waters comprise two stocks: an eastern Pacific stock that nests along the Pacific coast from Mexico to Colombia and a western Pacific stock that nests in coastal areas of southeastern Asia, New Guinea and northern Australia (NMFS and USFWS 1998e).

Olive ridleys, like leatherbacks, lead a primarily pelagic existence, however, they also forage in nearshore benthic habitats (Dutton 2004). Large juveniles and adults reside primarily within 100 km of the coast, and aggregate in large concentrations in coastal waters during the nesting season (Plotkin 1995). It is increasingly uncommon further offshore, and rare in the central Pacific, both at sea and around islands (Plotkin 1995). In Hawai'i this species is rare, but sightings are reportedly increasing (Balazs 1983). It has

been suggested that pelagic waters surrounding the Hawaiian Islands may serve as development habitat for animals from the Pacific coast of Mexico (Balazs 1983).

Olive ridley turtles appear to be omnivorous with crustaceans playing a major role. They feed on benthic organisms including bottom fish, crab, oysters, sea urchins, snails, tunicates, shrimp, and algae and pelagic species including jellyfish medusae, red crabs, and salps (Plotkin 1995; NMFS and USFWS 1998e). They can switch from one food type to another, e.g., bottom dwelling and water-column crustaceans, mollusks, fish, and salps, as it moves between habitats (Kopitsky et al. 2004). Olive ridley turtles have been documented feeding on crabs at a depth of 300m (NMFS and USFWS 1998e). Polovina et al. (2004) collected dive depth distribution data from satellite-linked dive recorders attached to two olive ridleys caught and released in the Hawai'i-based longline fishery. These data demonstrated that olive ridleys (compared with loggerheads) have a relatively deep dive pattern, spending only 20% of their time at the surface and over 40% of their time below 40 m. However, they tended to spend little time (10%) deeper than 100 m. One dive was recorded to 254 m.

Olive ridley turtles appear to have a bimodal diving pattern, with a number of short (presumably shallow) dives and longer dives (Beavers and Cassano 1996). Mean surface times from the same study were from 2.4 minutes at night and 2.9 minutes during the day, with a total range of 1-10 minutes. Olive ridley turtles off Australia had dives lasting up to 200 minutes in length (McMahon et al. 2007). Mean dive depths were between 20 and 46.7 m, but one individual dove to 150 m. These turtles appeared to be foraging on the bottom, and therefore the dive depths reflect the local environment rather than their ultimate diving capability. Migrating Olive ridley turtles had speeds ranging from 0.19 to 3.88 km/h with a mean of 1.28 km/h (Beavers and Cassano 1996).

Preferred nesting areas for Olive ridley turtles occur along continental margins and, rarely, on oceanic islands (NMFS and USFWS 1998e). With the exception of a single nesting in September 1985 on the island of Maui, Hawai'i (Balazs and Hau 1986), there is no nesting by this species anywhere in the United States or the territories under U.S. political jurisdiction (NMFS and USFWS 1998e). Nesting occurs throughout the year in the Eastern Tropical Pacific Ocean, with peak nesting months from September through December (NMFS and USFWS 1998e).

At sea in the eastern tropical Pacific, olive ridleys readily associate with objects floating in the water including anything from logs to plastic debris to dead whales (Pitman 1992; Arenas and Hall 1992), and appear strongly attracted to brightly colored objects (Arenas and Hall 1992). It is possible that young turtles move offshore and occupy areas of surface current convergences to find food and shelter among aggregated floating objects until they are large enough to recruit to the nearshore benthic feeding grounds of the adults (NMFS and USFWS 1998e).

The primary threat to these turtles in Hawaiian waters is incidental take in fisheries. Olive ridleys comprised 18% of the annual take of all species of sea turtles by the Hawai'i-based longline fishery observed from 1990 to 1994 (NMFS and USFWS 1998e). Over the period of 1994 to 1999, it was estimated that an annual average of 146 olive ridleys were caught in the Hawai'i-based longline fishery (McCracken 2000). Results to date in the fishery confirm the reduction in incidental catches of olive ridleys that can be achieved from the elimination of shallow sets. Beginning in April 2001, shallow sets were prohibited in the Hawai'i-based longline fishery. Data from the onboard observers in the longline fleet, which now comprise 20% of the fishing effort, showed that only two olive ridleys were caught from April through December 2001 (Polovina et al. 2003). The entanglement of juveniles and adults in marine debris around the Hawaiian Islands is reported from Kailua-Kona (Hawai'i), Puko'o (Moloka'i), Hana (Maui), and O'ahu (Balazs 1985).

The olive ridley is listed as "threatened" under the ESA in the Pacific, except for the Mexican nesting population, which is classified as "endangered" due to over-harvesting. It is classified as "endangered" under the IUCN and is listed in Appendix I of CITES (CITES 2005).

2.0 CETACEANS

Background/Literature Review

The Hawaiian Islands make up the most isolated archipelago in the world. At least 18 species of odontocetes and 5 mysticetes are regularly or occasionally found in Hawaiian waters (Carretta et al. 2004; Barlow 2006). While our knowledge of the ecology of many cetacean species in Hawai'i has increased in recent years (e.g. Maldini et al. 2005; Barlow 2006), currently, there is very little known about the status, numbers, distribution and life histories of many of these species (e.g., Carretta et al. 2004). For example, the degree of insularity of most, if not all, Hawaiian cetacean stocks is an important question, which remains unresolved.

It has been suggested that higher-densities of odontocete species, close to the islands, may represent reproductively-isolated "resident" populations of animals, rather than aggregations of individuals from a broader oceanic population (Andrews et al. 2006; Baird et al. 2005b). Sparse, and generally short-lived, genetic and photo-identification studies have been conducted in Hawai'i to investigate such questions. Genetic information is available for only a few species, but suggests that some degree of reproductive isolation exists between Hawaiian and other populations of spinner dolphins, false killer whales, short-finned pilot whales and killer whales (Andrews et al. 2006; Chivers et al. 2003; Chivers et al. In Press; Baird et al. 2006a). Furthermore, while there is apparently inter-island movements of false killer whales (Baird et al. 2005a) and melon-headed whales (Huggins et al. 2005) (at least within the leeward Hawaiian Islands), work with spinner dolphins (Andrews et al. 2006), bottlenose dolphins (Baird et al. 2002, 2003; Martien et al. 2005), pygmy killer whales (McSweeney et al. 2005) and likely rough-toothed dolphins (Webster et al. 2005) suggests little or no movement of animals between islands. Thus, differentiation of populations may even be occurring within the Hawaiian Island chain. High site fidelity is likely paired with small population sizes for rough-toothed dolphins (Webster et al. 2005), dwarf sperm whales (Baird et al. 2006b) and pygmy killer whales (McSweeney et al. 2005), along the western coast of the island of Hawai'i.

Table 1. List of Cetacean Species

Common name	Scientific name
Blainville's beaked whale	*Mesoplodon densirostris*
Blue whale	*Balaenoptera musculus*
Bottlenose dolphin	*Tursiops truncatus*
Bryde's whale	*Balaenoptera edeni*
Cuvier's beaked whale	*Ziphius cavirostris*
Dwarf sperm whale	*Kogia sima*
False killer whale	*Pseudorca crassidens*
Fin whale	*Balaenoptera physalus*
Fraser's dolphin	*Lagenodelphis hosei*
Humpback whale	*Megaptera novaeangliae*
Killer whale	*Orcinus orca*
Longman's beaked whale	*Indopacetus pacificus*
Melon-headed whale	*Peponocephala electra*
North Pacific minke whale	*Balaenoptera acutorostrata*
Pantropical spotted dolphin	*Stenella attenuata*
Pygmy killer whale	*Feresa attenuata*
Pygmy sperm whale	*Kogia breviceps*
Risso's dolphin	*Grampus griseus*
Rough-toothed dolphin	*Steno bredanensis*
Sei whale	*Balaenoptera borealis*
Short-finned pilot whale	*Globicephala macrorhynchus*
Sperm whale	*Physeter macrocephalus*
Spinner dolphin	*Stenella longirostris*
Striped dolphin	*Stenella coeruleoalba*

2.1 Mysticetes

Blue Whale (*Balaenoptera musculus*):

Blue whales are found in tropical to polar waters worldwide (Carretta et al. 2004). In the North Pacific, the IWC only recognizes one stock (Donovan 1991). However, recent analyses of acoustic data obtained throughout the North Pacific Ocean (Stafford et al. 2001; Stafford 2003) has revealed two distinct blue whale call types, suggesting two North Pacific stocks: eastern and western. Blue whales belonging to the western Pacific stock appear to feed in summer southwest of Kamchatka, south of the Aleutians, and in the Gulf of Alaska (Stafford 2003; Watkins et al. 2000), and in winter they migrate to lower latitudes in the western Pacific and less frequently in the central Pacific, including Hawai'i (Stafford et al. 2001). There has been one published sighting record of blue whales near Hawai'i and two sightings have been made by observers on Hawai'i-based longline vessels (Carretta et al. 2004). Additional evidence that blue whales occur in this area comes from acoustic recordings made off O'ahu and Midway Atoll (Northrop et al. 1971; Thompson and Friedl 1982), which included at least some within the U.S. EEZ. The recordings made off Hawai'i showed bimodal peaks throughout the year (Stafford et al. 2001), with western Pacific call types heard during winter and eastern Pacific calls heard during summer. For management purposes under the Marine Mammal Protection Act (MMPA), two stocks are considered to occur in U.S. waters of the North Pacific: North Pacific and the western North Pacific, which includes whales found around the Hawaiian Islands during winter.

No blue whale sightings were made during twelve aerial surveys conducted in 1993-98 within about 25 nmi of the main Hawaiian Islands (Mobley et al. 2000), nor during a summer/fall 2002 shipboard surveys of the entire Hawaiian Islands EEZ (Barlow 2006). No estimate of abundance is available for the western Pacific blue whale stock (Carretta et al. 2004).

This species has been protected in the North Pacific by the IWC since 1966. They are listed in Appendix I of the CITES (CITES 2005). Blue whales are formally listed as "endangered" under the ESA, and consequently the Hawaiian stock is automatically considered as a "depleted" and "strategic" stock under the MMPA.

The swimming and diving behavior of blue whales has been relatively well characterized. The average surface speed for a blue whale is 4.5 km/h (2.4 knots) (with a maximum speed of 7.2 km/h (3.9 knots) (Mate et al., 1999). Dive times range from 4 to 15 min (Laurie, 1933; Croll et al., 2001b). Dive depths average 140 m (460 ft). Blue whales typically make 5 to 20 shallow dives at 12 to 20-second intervals followed by a deep dive of 3 to 30 min (Yochem and Leatherwood, 1985; Croll et al., 1999). The dive depth of foraging blue whales averages 67.6 m (222 ft) (Croll et al., 2001b). Blue whales foraging off California were found to have a mean dive duration ranging from 4 to near 10 min (Strong, 1990). Blue whales feed almost exclusively on euphausiids, or krill (Fiedler et al., 1998; Sears, 2002).

There is no direct measurement of auditory threshold for the hearing sensitivity of blue whales (Ketten 2000). In one of the only studies to date, no change in blue whale vocalization pattern or movement relative to an LFA sound source was observed for RLs of up to approximately 155 dB re 1 μPa (Aburto et al. 1997).

Blue whales produce a variety of LF sounds in a 10 to 200 Hz band (Edds, 1982; Thompson and Friedl, 1982; Alling and Payne, 1991; Clark and Fristrup, 1997; Rivers, 1997; Stafford et al., 1998, 1999a, 1999b, 2001). The Eastern Pacific population of blue whales produce at least four unique sounds that have been described previously, the pulse A call and tonal B call, and downsweeps known as D calls (Thompson et al. 1996; McDonald et al. 2001). The A and B calls occur in repetitive patterns that have been classified as song. In the Eastern North Pacific, the amplitude modulated A part typically lasts 17 seconds and has a fundamental frequency of 16 Hz. The frequency modulated B

part lasts about 19 seconds that sweeps down from ~ 18 Hz to ~ 15 Hz. There are often strong harmonics that accompany the fundamental frequency. This blue whale song appears to be produced only by males (McDonald et al. 2001; Oleson et al. 2007) and may function as a reproductive display. Song was recorded solely from traveling animals, while animals that produced individual A or B calls could be engaged in a variety of behavioral states (Oleson et al. 2007). Songs are produced throughout the year and there are distinct structural differences in the songs of different populations (McDonald et al. 2006). The D calls are known to be produced by both sexes, frequently during foraging (Oleson et al. 2007). The blue whale is one of the loudest baleen whales with maximum estimated SLs ranging between 180 and 190 dB re 1 μPa at 1m (Cummings and Thompson, 1971; Aroyan et al., 2000 (McDonald et al. 2001).

Blue whale song has been recorded over the entire migratory path, from the Gulf of Alaska south to Mexico and the Costa Rica dome (Stafford et al. 2001; Stafford 2003; Burtenshaw et al. 2004). Croll et al. (2001a) studied the effects of anthropogenic low-frequency noise on the foraging ecology of blue and fin whales off San Nicolas Island, California. Blue and fin whales produce long, intense patterned sequences of signals in the band of 10 to 100 Hz. These signals have been recorded over ranges of hundreds of miles. This study examined the response of blue and fin whales to human-produced low-frequency sounds at RLs greater than 120 dB produced by SURTASS LFA sonar. The blue and fin whale sightings did not appear to be randomly distributed and did not appear to be related to the sound source. No clear trends appeared in vocalization rates. There was no significant change in vocal activity in the study area or obvious responses of blue or fin whales in the presence of LF sound. It is possible that the brief interruption of normal behavior or short-term physiological responses to LF noise at RLs of approximately 140 dB re 1 μPa have few implications on survival and reproductive success. Long-term effects, however, could have more significant effects, but these effects are harder to identify and quantify (Croll et al., 2001a).

Bryde's Whale (*Balaenoptera edeni*):

Bryde's whales are distributed worldwide in tropical and warm temperate waters and several stocks are recognized. It is one of the least known of the large whales and its population size is virtually unknown (Cummings 1985). Confusion of this species with sei whales has been widespread, leading to uncertainties about the exact distribution of both species in the areas of overlap (Klinowska and Cooke 1991).

Shallenberger (1981) reported a sighting of a Bryde's whale southeast of Nihoa in April 1977 (see DeLong and Brownell 1977; Leatherwood et al. 1982). Leatherwood et al. (1982) described the species as relatively abundant in summer and fall on the Mellish and Miluoki banks northeast of Hawai'i and around Midway Atoll, but the basis for this statement was not explained. Ohsumi and Masaki (1975) reported the tagging of "many" Bryde's whales between the Bonin and Hawaiian Islands in the winters of 1971 and 1972 (Ohsumi 1977). A shipboard survey of U.S. EEZ waters of the Hawaiian Islands in 2002 resulted in 13 Bryde's whale sightings throughout the study area (Barlow 2006). With presently available evidence, there is no biological basis for defining separate stocks of Bryde's whales in the central North Pacific.

For management purposes under the MMPA, two stocks of Bryde's whales are recognized within the Pacific U.S. EEZ of the eastern Pacific: 1) Hawaiian, and 2) the ETP (east of 150°W and including the Gulf of California and waters off California).

An estimate of 13,000 (CV=0.20) Bryde's whales in the ETP was made from vessel surveys between 1986 and 1990 (Wade and Gerrodette 1993). The area to which this estimate applies is mainly east and somewhat south of the Hawaiian Islands, and it is not known whether these animals are part of the same population that occurs around the Hawaiian Islands (Carretta et al. 2004).

No Bryde's whale sightings were made during twelve aerial surveys conducted in 1993, 1995 and 1998 within about 25 nmi of the main Hawaiian Islands (Mobley et al. 2000). A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 3,215 (CV=0.59) Bryde's whales (Barlow 2006). This is currently the best available abundance estimate for this stock.

Bryde's whales are listed in Appendix I of CITES (CITES 2005). They are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA.

The swim speed of a Bryde's whale has been recorded at 20 km/h (10.8 knots) (Cummings, 1985), and they dive for as long as 20 min, although dive depths are not known. Bryde's whales feed primarily on euphausiids, copepods, and schooling fish such as sardines, herring, pilchard, and mackerel (Best, 1960; Nemoto and Kawamura, 1977; Cummings, 1985; Tershy, 1992; Tershy et al., 1993).

There is no direct measurement of auditory threshold for the hearing sensitivity of Bryde's whales. Recordings off California have revealed that Bryde's whales make short low-frequency moans. Moans are between 70 and 245 Hz and last between 0.2 and 1.5 sec. Source levels range between 152 and 174 dB re 1 µPa at 1m (Cummings et al. 1986). Bryde's whales also make a pulsed moan, which ranges between 100 and 900 Hz and between 0.5 and 51 sec in duration. The pulse rate varies between adults and calves (Edds et al. 1993). Finally, calves have been recorded making a series of discrete pulses between 700 and 900 Hz. These were recorded from calves when the adult was diving and from a captive juvenile (Edds et al. 1993). Bryde's whales in the Eastern Tropical Pacific produce at least six different call types. Most of these are lower in frequency than the earlier recordings, between 20 and 60 Hz, with one type being frequency downsweep from 207 to 75 Hz. Durations ranged from 1.1 to 4.9 seconds (Oleson et al. 2003).

Fin Whale (*Balaenoptera physalus*):

The fin whale occurs in all major oceans worldwide and seasonally migrates between temperate and polar waters (Gambell 1985). Balcomb (1987) observed 8-12 fin whales in a multi-species feeding assemblage on 20 May 1966 approximately 250 mi. south of Honolulu. Additional sightings were reported north of O'ahu in May 1976 and in the Kaua'i Channel in February 1979 (Shallenberger 1981). More recently, a single fin whale was observed north of Kaua'i in February 1994 (Mobley et al. 1996), and five sightings were made during a 2002 survey of waters within the U.S. EEZ of the Hawaiian Islands (Barlow 2006). A single stranding has been reported on Maui (Shallenberger 1981). Thompson and Friedl (1982; and see Northrop et al. 1968) suggested that fin

whales migrate into Hawaiian waters mainly in fall and winter, based on acoustic recordings off O'ahu and Midway Atoll. More recently, McDonald and Fox (1999) reported an average of 0.027 calling fin whales per 1000^2 km (grouped by 8-hr periods) based on passive acoustic recordings within about 16 km of the north shore of O'ahu.

In the North Pacific, the IWC recognizes two stocks of fin whales, the east China Sea and the rest of the North Pacific (Donovan 1991). Mizroch et al. (1984) cites evidence for additional fin whale subpopulations in the North Pacific. For management purposes under the MMPA, three stocks of fin whales are recognized in the North Pacific: 1) Hawaiian, 2) California/Oregon/Washington, and 3) Alaskan.

A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 174 (CV=0.72) fin whales (Barlow 2003b). This is currently the best available abundance estimate for this stock (Carretta et al. 2004).

Fin Whales have been protected in the North Pacific by the IWC since 1976. They are listed in Appendix I of the CITES (CITES 2005). Fin whales are formally listed as "endangered" under the ESA, and consequently the Hawaiian stock is automatically considered as a "depleted" and "strategic" stock under the MMPA.

Swimming speeds average between 1 to 16 km/h (Watkins, 1981). Fin whales have a mean dive time of 4.2±1.67 min at depths averaging 60 m (197 ft) (Panigada, 1999; Croll et al., 2001a). Maximum dive depths have been recorded deeper than 360 m (1,181 ft) (Charif et al., 2002). Similar to blue whales, fin whales typically make 5-20 shallow dives at 13-20 second intervals, followed by a deep dive of 1.5-15 min (Strong, 1990; Croll et al., 1999). Fin whales forage at dive depths close to 100 m (328 ft) deep. Foraging dive times range from 5 to 8 min and fin whales feed primarily upon planktonic crustaceans (particularly euphausiids), fish and squid (Gambell, 1985a; Aguilar, 2002).

There is no direct measurement of auditory threshold for the hearing sensitivity of fin whales (Ketten, 2000; Thewissen, 2002). Fin whales produce a variety of LF sounds in the 10 to 200 Hz band (Watkins, 1981; Watkins et al., 1987; Edds, 1988; Thompson et al., 1992). Short sequences of rapid FM calls in the 20-70 Hz band are associated with animals in social groups (Watkins, 1981; Edds, 1988; McDonald et al., 1995. The most typical signals are long, patterned sequences of low and infrasonic pulses in the 18-35 Hz range (Patterson and Hamilton, 1964; Watkins et al., 1987; Clark et al., 2002). This sound is referred to as a "20-Hz pulse." The seasonality of the pattern of bouts suggests that these are male reproductive displays or displays associated with food resources (Watkins et al., 1987; Clark et al., 2002; Croll et al., 2002) while the individual counter-calling sounds suggest that the more variable calls are contact calls (McDonald et al. 1995). Estimated SLs are as high as 180 to 190 dB (Patterson and Hamilton, 1964; Watkins et al., 1987; Thompson et al., 1992; McDonald et al., 1995; Charif et al., 2002; Croll et al., 2002).

Croll et al. (2001a) studied the effects of anthropogenic low-frequency noise on the foraging ecology of blue and fin whales off San Nicolas Island, California. This study is described above in the blue whale section.

Humpback Whale (*Megaptera novaeangliae*):

The humpback whale has a cosmopolitan distribution, occurring in all ocean basins, although it is less common in Arctic waters. There has been a prohibition on taking humpback whales since 1966. Population estimates for the entire North Pacific have increased substantially from 1,200 in 1966 to 6,000-8,000 circa 1992 (Carretta et al. 2004).

Although the IWC only recognizes a single stock in the North Pacific (Donovan 1991), there is good evidence for multiple populations of humpback whales (Johnson and Wolman 1984; Baker et al. 1990). At present, three MMPA management units of humpback whales are recognized within the U.S. EEZ of the North Pacific: 1) the eastern North Pacific stock, wintering in coastal Mexico; 2) the central North Pacific stock, wintering in the Hawaiian Islands; and 3) the western North Pacific stock, wintering in Japanese waters (Carretta et al. 2004). In general, fidelity to breeding and feeding areas is high, but interchange occurs at low levels between breeding areas and between feeding areas.

The humpback whales that winter in Hawai'i are part of the central North Pacific (CNP) stock which is comprised of whales that summer in discrete feeding aggregations along the Pacific rim from northern British Columbia and Alaska, west to Unimak Pass (Baker et al. 1994; Calambokidis et al. 1997, 2001). This stock is listed as "endangered" under the ESA and "depleted" under the MMPA. It is therefore classified as a strategic stock. It is listed in Appendix I of CITES (CITES 2005).Calambokidis et al. (1997) estimated 4,005 (CV = 0.095) humpback whales in the CNP stock based on photo-identification data, with a current rate of increase of 7-10% per year (Mobley et al. 2001; Mizroch et al. 2004).

Threats to the CNP stock are difficult to quantify due to a lack of data, but include serious injury and mortality resulting from interactions with fishing gear, ship strikes, habitat degradation and vessel disturbance. In Hawai'i, data from 1972 to 1996 reveal at least six entanglements of humpback whales and one death due to vessel strike (Mazzuca et al. 1998). These data also indicate an increasing trend of entanglement in natural fiber and synthetic lines in Hawai'i since 1992 and a three-fold increase in death and entanglement occurrences related to human activity in 1996. Increasing levels of anthropogenic noise in the world's oceans have also been identified as a habitat concern for baleen whales that communicate using low- and mid-frequency sound (e.g. Richardson et al. 1995).

Mean humpback whale swim speeds during migration are near 4.5 km/h (2.4 knots) (Gabriele et al. 1996). Dive times recorded off southeast Alaska are near 3 to 4 min in duration (Dolphin, 1987). In the Gulf of California, humpback whale dive times averaged 3.5 min (Strong, 1990). The deepest recorded humpback dive was 240 m (790 ft) (Hamilton et al., 1997). Dives on feeding grounds ranged from 2 to 5 min (Dolphin, 1987; Croll, et al., 1999). Dive depths average near 40 m (131 ft). Humpbacks eat a wide variety of prey including schooling fish and krill, which are likely found above 300 m (1,000 ft) (Hamilton et al., 1997).

There is no direct measurement of auditory threshold for the hearing sensitivity of humpback whales (Ketten 2000; Thewissen 2002). Because of this lack of auditory sensitivity information, Houser et al. (2001a) developed a mathematical function to

describe the frequency sensitivity by integrating position along the humpback basilar membrane with know mammalian data. The results predicted the typical U-shaped audiogram with sensitivity to frequencies from 700 Hz to 10 kHz with maximum sensitivity between 2 to 6 kHz. Humpback whales have been observed reacting to LF industrial noises at estimated RLs of 115-124 dB (Malme et al., 1985). They have also been observed to react to playback of conspecific calls at RLs as low as 102 dB (Frankel et al., 1995). Playbacks of 75 Hz signals to humpbacks resulted in a very slight increase in their dive times as well as time spent submerged (Frankel and Clark 1998; Frankel and Clark 2000). The received sound levels ranged from 90 to 130 dB re 1 μPa, and the change in behavior resulting from these levels was less than that resulting from the nearest vessel (Frankel and Clark 1998).

Humpbacks produce a great variety of sounds that fall into three main groups: 1) sounds associated with feeding, 2) sounds made within groups on winter grounds, and 3) songs associated with reproduction. These vocalizations range in frequency from 20 to 10,000 Hz. Feeding groups produce distinct repeated sounds ranging from 20 to 2,000 Hz, with dominant frequencies near 500 Hz (Thompson et al., 1986; (Frankel 2002). These sounds are attractive and appear to rally animals to the feeding activity (D'Vincent et al., 1985; Sharpe and Dill, 1997). Feeding sounds were found to have SLs in excess of 175 dB (Thompson et al., 1986; Richardson et al., 1995).

Social sounds in the winter breeding areas are produced by males and extend from 50 Hz to more than 10,000 Hz with most energy below 3000 Hz (Tyack and Whitehead, 1983; Richardson et al., 1995). These sounds are associated with agonistic behaviors from males competing for dominance and proximity to females. They have shown to elicit reactions from animals up to 9 km (4.9 nm) away (Tyack and Whitehead, 1983).

During the breeding season, males sing long, complex songs with frequencies between 25 and 5,000 Hz. Mean SLs are 165 dB (broadband), with a range of 144 to 174 dB (Payne and Payne, 1971; Frankel et al., 1995; Richardson et al., 1995; (Tyack and Clark 2000). The songs vary geographically among humpback populations and appear to have an effective range of approximately 10 to 20 km (5.4 to 10.8 nm) (Au et al. 2000). Singing males are typically solitary and maintain spacing of 5 to 6 km (2.7 to 3.2 nm) apart (Tyack, 1981; Frankel et al., 1995). Songs have been recorded on the wintering ground, along migration routes, and less often on northern feeding grounds (Richardson et al., 1995; Gabriele and Frankel 2002). A song is a series of sounds in a predictable order. The humpback songs are typically about 15 min long and are believed to be a mating-related display performed only by males.

North Pacific Minke Whale (*Balaenoptera acutorostrata*):

The minke whale has a cosmopolitan distribution in polar, temperate and tropical waters worldwide (Carretta et al. 2004). Several stocks are recognized around the world. The IWC recognizes three stocks of minke whales in the North Pacific: one in the Sea of Japan/East China Sea, one in the rest of the western Pacific west of 180°N, and one in the remainder of the Pacific (Donovan 1991). Although reliable abundance estimates do not exist for several of the stocks, the worldwide population size of minke whales is likely in the hundreds of thousands.

Minke whales have only been recently confirmed to occur seasonally (about November - March) around the Hawaiian Islands (Carretta et al. 2004; Barlow 2006), and their migration routes or destinations are not known. Four reliable sightings of minke whales were made by observers in the Hawai'i-based longline fishery during the months of December-March, 2000-2002 (Carretta et al. 2004). One confirmed sighting of a minke whale was made in November 2002 during a survey of waters within the U.S. EEZ of the Hawaiian Islands (Rankin and Barlow 2005; Barlow 2006). There are no known stranding records of this species from the main islands (Nitta 1991; Maldini et al. 2005). For management purposes under the MMPA, there are three stocks of minke whale recognized within the Pacific U.S. EEZ: 1) Hawaiian, 2) California/Oregon/ Washington, and 3) Alaskan.

A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in one 'off effort' sighting of a minke whale (Barlow 2006), following the acoustic detection of the so-called "boing" sound, which is now be attributed to the North Pacific minke whale (Rankin and Barlow 2005). This sighting was not part of regular survey operations and, therefore, could not be used to calculate an estimate of abundance (Barlow 2006). Furthermore, the majority of this survey took place during summer and early fall, when the Hawaiian stock of minke whale would be expected to be farther north. There currently is no abundance estimate for this stock of minke whales.

Minke whales are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA. Minke whales are listed in Appendix I of CITES (CITES 2005). The increasing levels of anthropogenic noise in the world's oceans have been suggested to be a habitat concern for whales (e.g. Richardson et al. 1995).

Normal swimming speeds of minke whales have been reported as 6.1 km/h (3.3 knots) (Lockyer, 1981). Dive times range from 1.5 to 7 min (Stewart and Leatherwood, 1985), but dive depths are not well known. Minke whales generally feed on small schooling fish, euphausiids, and copepods. They specialize their diet both seasonally and geographically based on prey availability (Stewart and Leatherwood, 1985).

There is no direct measurement of auditory threshold for the hearing sensitivity of minke whales (Ketten, 2000; Thewissen, 2002). Minke whales produce a variety of sounds, primarily moans, clicks, downsweeps, ratchets, thump trains, and grunts in the 80 Hz to 20 kHz range (Winn and Perkins, 1976; Thompson et al., 1979; Edds-Walton, 2000; Mellinger and Clark, 2000; Frankel, 2002). Complex vocalizations recorded from Australian minke whales involved pulses ranging between 50 and 9,400 Hz, followed by pulsed tones at 1,800 Hz and tonal calls shifting between 80 and 140 Hz (Gedamke et al., 2001)

Minke whales have been identified as the source of the "boing" signal. There are distinct differences between these signals in the eastern and central portions of the Pacific. Central Pacific boings has a pulse repetition rate of 115 s-1 and last approximately 2.6 whereas eastern Pacific boings has a pulse repetition rate of 92 s-1 and last approximately 3.6 (Rankin and Barlow 2005). The central Pacific type will be found around Hawai'i.

Sei Whale (*Balaenoptera borealis*):

Sei whales are distributed far out to sea in temperate regions of the world and do not appear to be associated with coastal features (Carretta et al. 2004). They are not found as far into polar waters as the other rorquals (Gambell 1985). In the North Pacific, the IWC recognizes only one stock of sei whales (Donovan 1991), but some evidence exists for multiple populations (Masaki 1977; Mizroch et al. 1984; Horwood 1987). Six sightings of sei whales were recently made during a summer/fall 2002 shipboard survey of waters within the U.S. EEZ of the Hawaiian Islands (Barlow 2006). For management purposes under the MMPA, sei whales within the Pacific U.S. EEZ are divided into three discrete, stocks: 1) Hawai'i 2) California, Oregon and Washington, and 3) Alaska.

Sei whales were estimated to have been reduced to 20% (8,600 out of 42,000) of their pre-whaling abundance in the North Pacific (Tillman 1977). There have been no direct estimates of sei whale abundance in the entire North Pacific based on sighting surveys. Twelve aerial surveys conducted within about 25 nmi of the main Hawaiian Islands in 1993-98 (Mobley et al. 2000) resulted in no sightings of sei whales. The 2002 shipboard survey resulted in a summer/fall abundance estimate of 77 (CV=1.06) sei whales (Barlow 2003b). This is currently the best available abundance estimate for this stock, but the majority of sei whales would be expected to be at higher latitudes in their feeding grounds at this time of year (Carretta et al. 2004).

There has been an IWC prohibition on taking sei whales since 1976, and commercial whaling in the U.S. has been prohibited since 1972. They are listed in Appendix I of CITES (CITES 2005). Sei whales are formally listed as "endangered" under the ESA, and consequently the Hawaiian stock is automatically considered as a "depleted" and "strategic" stock under the MMPA. A possible habitat concern for sei whales is the increasing levels of anthropogenic noise that may affect their communication (Richardson et al. 1995).

Swim speeds have been recorded at 4.6 km/h (2.5 knots). Dive times range from 0.75 min to 15 min, with a mean duration of 1.5 min (Schilling et al., 1992). Sei whales make shallow, foraging dives of 20 to 30 m (65 to 100 ft) followed by a deep dive up to 15 min in duration (Gambell, 1985b). They feed predominantly on copepods in the higher latitudes and schooling fish in the lower latitudes (Jonsgård and Darling, 1977; Rice, 1977; Nemoto and Kawamura, 1977; Kawamura, 1994; Sigurjonsson, 1995).

There is no direct measurement of auditory threshold for the hearing sensitivity of sei whales (Ketten, 2000; Thewissen, 2002). Few sounds have been recorded from sei whales. Knowlton et al. (1991) and Thompson et al. (1979) recorded rapid sequences of FM pulses in the 1.5 to 3.5 kHz range near groups of feeding sei whales during the summer off eastern Canada. Sei whales in the Antarctic produced low-frequency tonal signals and FM sweeps as well as broadband sounds that were markedly different from the mid-frequency signals recorded in the northern hemisphere (McDonald et al. 2005). Tonal calls occurred as single occurrence, or as two, three, or four parts. Each part of a call was short, with a mean duration of 0.45 seconds with a mean frequency of 433 Hz. The FM sweeps had a mean duration of 1.1 seconds and were centered around 432 Hz. The maximum source level for these calls was reported as 156 dB re 1 µPa at 1 m (McDonald et al. 2005).

2.2 Odontocetes

Blainville's Beaked Whale ***(Mesoplodon densirostris):***

Estimating the abundance and density of beaked whales is more difficult than for most other cetacean species, because beaked whales spend so much of their time submerged and field identification is difficult (Barlow et al. 2006). Blainville's beaked whale has a cosmopolitan distribution in tropical and temperate waters, apparently the most extensive known distribution of any Mesoplodon species (Mead 1989). Two strandings were reported in 1961 from Midway Atoll (Galbreath 1963) and another in 1983 from Laysan Island (Nitta 1991). Sixteen sightings were reported from the main islands by Shallenberger (1981), who suggested that Blainville's beaked whales were present off the Waianae Coast of O'ahu for prolonged periods annually. Three sightings were made during a 2002 shipboard survey of waters within the U.S. Exclusive Economic Zone (EEZ) of the Hawaiian Islands (Barlow 2006). While nothing is known about stock structure, some genetic samples have been collected recently from around the main Hawaiian Islands, and photo-identification studies have suggested long-term sight fidelity for the west side of the island of Hawai'i (McSweeney et al. 2007). For management purposes under the MMPA, three Mesoplodon stocks are defined within the Pacific U.S. EEZ: 1) *M. densirostris* in Hawaiian waters, 2) *M. stejnegeri* in Alaskan waters, and 3) all Mesoplodon species off California, Oregon and Washington.

Aerial surveys were flown within 25 nmi of the main Hawaiian Islands in 1993, 1995 and 1998 and resulted in an abundance estimate of 68 (CV=0.60) Blainville's beaked whales for the Hawaiian stock (Mobley et al. 2000). This is an underestimate of the stock's abundance because areas around the Northwestern Hawaiian Islands (NWHI) and beyond 25 nautical miles from the main islands were not surveyed (Carretta et al. 2004). Furthermore, this species is known to spend a large proportion of time diving, causing additional downward bias in the abundance estimate (Baird et al. 2005b). A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 2,872 (CV=1.25) Blainville's beaked whales (Barlow 2006), including a correction factor for missed diving animals. This is currently the best available abundance estimate for this stock.

Between 1994 and 2002, at least one Blainville's beaked whale was observed hooked and killed in the Hawai'i-based longline fishery, with approximately 4-25% of all fishing effort observed (Forney 2004). In recent years, there has been increasing concern that loud underwater sounds, such as active sonar and seismic operations, may be harmful to beaked whales (Malakoff 2002). The use of active sonar from military vessels has been implicated in mass strandings of beaked whales in the Mediterranean Sea during 1996 (Frantzis 1998), the Bahamas during 2000 (Balcomb and Claridge 2001), and the Canary Islands 2002 (Martel 2002). Similar military active sonar operations may occur around the Hawaiian Islands but are unlikely near Honokohau Bay. No estimates of potential mortality or serious injury are available for U.S. waters (Carretta et al. 2004).

Blainville's beaked whales are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA. The Hawaiian stock of Blainville's beaked

whales is not considered strategic under the MMPA because the estimated rate of fisheries related mortality or serious injury within the Hawaiian Islands EEZ (0.8 animals per year) is less than the PBR (9.6) (Carretta et al. 2004).

General swim speeds for ziphiids have averaged 5 km/h (2.7 knots) (Kastelein and Gerrits, 1991). Dives of Blainville's beaked whales averaged 7.47 min during social interactions at the surface (Baird et al. 2004). Dives over 45 min have been recorded for some species in this genus (Jefferson et al., 1993). Dive depths are variable among species and not well documented.

Mesoplodon whales are deep diving species which consume small cephalopods and bentho-pelagic fish ((Sullivan and Houck 1979); Leatherwood et al., 1988; (Mead 1989); Jefferson et al., 1993; (MacLeod et al. 2003). Blainville's beaked whales diving to depths near 900 m (2625 ft) for 20 min or longer are most likely foraging (Leatherwood et al., 1988; (Baird et al. 2004).

There is no direct measurement of auditory threshold for the hearing sensitivity of *Mesoplodon* species (Ketten, 2000; (Thewissen 2002). There are sparse data available on the sound production of *Mesoplodon* species. A stranded Blainville's beaked whale in Florida produced chirps and whistles below 1 kHz up to 6 kHz (Caldwell and Caldwell, 1971a). More recent studies on Cuvier's beaked whales and Blainville's beaked whales conducted by Johnson et al. (2004) concluded that no vocalizations were detected from any tagged beaked whales when they were within 200 m (656.2 ft) of the surface. The Blainville's beaked whale started clicking at an average depth of 400 m (1312.3 ft), ranging from 200 to 570 m (656.2 to 1870.1 ft), and stopped clicking when they started their ascent at an average depth of 720 m (2362.2 ft), with a range of 500 to 790 m (1640.4 to 2591.9 ft). The intervals between regular clicks were approximately 0.4 second. Trains of clicks often end in a rapid increase in the click rate, which is also called a buzz. Both the Cuvier's beaked whale and the Blainville's beaked whale have a somewhat flat spectrum that was accurately sampled by Johnson et al. between 30 and 48 kHz. There may be a slight decrease in the spectrum above 40 kHz, but the 96 kHz sampling rate was not sufficient to sample the full frequency range of clicks from either of the species (Johnson et al., 2004).

Bottlenose Dolphin (*Tursiops truncatus*):

Bottlenose dolphins are distributed worldwide in tropical and warm-temperate waters (Carretta et al. 2004). In many regions, separate coastal and offshore forms are known (Walker 1981; Ross and Cockcroft 1990; Van Waerebeek et al. 1990). In Hawaiian waters, onshore-offshore forms of bottlenose dolphins may exist, but currently only one stock is recognized in this area. In U.S. Pacific EEZ, the following three stocks are recognized for management purposes under the MMPA: 1) Hawaiian, 2) California, Oregon and Washington offshore, and 3) California coastal.

Bottlenose dolphins are relatively common throughout the Hawaiian Islands, from the island of Hawai'i to the Kure Atoll (Shallenberger 1981). In the NWHI, they are found primarily in relatively shallow inshore waters (Rice 1960). In the main Hawaiian Islands, they are found in both shallow inshore waters and deep channels between islands. However, relative to survey effort, they occur primarily inshore of 500 m (Baird et al. 2003). Off the islands of Kaua'i and Ni'ihau, bottlenose dolphins are found out to at least 900 m depth, but, extensive survey efforts in waters deeper than 1500 m around the main islands resulted in no sightings (Baird et al. 2003). Fifteen strandings have been reported in the main Hawaiian Islands (Nitta 1991; Maldini et al. 2005; M. Breese, pers. comm.).

Photographic identification surveys suggest that there is no movement of animals between the island groups of 1) Hawai'i, 2) Maui, Moloka'i, Lana'i and Kaho'olawe, 3) O'ahu and 4) Kaua'i and Ni'ihau (Baird et al. 2003). There is also a bimodal depth distribution in sightings off Kaua'i and Ni'ihau, suggesting separate shallow and deep-water populations. In their analysis of sightings of bottlenose dolphins in the eastern tropical Pacific (ETP), Scott and Chivers (1990) noted that there was a large hiatus between the westernmost sightings and the Hawaiian Islands. These data suggest that bottlenose dolphins in Hawaiian waters belong to a separate stock from those in the ETP (Martien et al. 2005).

Photographic mark-recapture studies off Maui and Lana'i estimated 134 (95% C.I. 107- 180) bottlenose dolphins inhabiting that area (Baird et al. 2002). More recently, a minimum of 219 distinct bottlenose dolphins were identified around all the main Hawaiian Islands (Baird et al. 2003). The Hawaiian stock was estimated at 743 (CV=0.56) animals based on twelve aerial surveys conducted in 1993, 1995 and 1998 (Mobley et al. 2000). This abundance underestimates the total number of bottlenose dolphins within the U.S. EEZ off Hawai'i, because areas around the NWHI and beyond 25 nmi from the main Hawaiian Islands were not surveyed (Carretta et al. 2004). A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 3,215 (CV=0.59) bottlenose dolphins (Barlow 2006). This is currently the best available abundance estimate for this stock.

Interactions with cetaceans have been reported for all Hawaiian pelagic fisheries, and some of these interactions involved bottlenose dolphins (Nitta and Henderson 1993). Between 1994 and 2002 two bottlenose dolphins were observed hooked or entangled in the Hawai'i-based longline fishery outside of U.S. EEZ waters, with approximately 4-25% of all effort observed (Forney 2004). During the 905 observed trips with 11,014 sets, the average interaction rate of bottlenose dolphins was one animal per 905 fishing trips, or one animal per 11,014 sets. Both animals caught were considered seriously injured (Forney 2004), based on an evaluation of the observer's description of the interaction and following established guidelines for assessing serious injury in marine mammals (Angliss and Demaster 1998). Average 5-yr estimates of annual mortality and serious injury for 1998-2002 are 5.8 (CV = 1.00) bottlenose dolphins outside of U.S. EEZs, and none within U.S. EEZs. Several additional unidentified cetaceans, which may have been bottlenose dolphins, were also taken in this fishery (Forney 2004).

Bottlenose dolphins are one of the species commonly reported to take bait and catch from several Hawaiian sport and commercial fisheries (Nitta and Henderson 1993; Schlais 1984; S. Yin, pers. obs.). Observations of bottlenose dolphins taking bait or catch have also been made in the day handline fishery (palu-ahi) for tuna, the handline fishery for mackerel scad, the troll fishery for billfish and tuna, and the inshore set gillnet fishery (Nitta and Henderson 1993). Nitta and Henderson (1993) indicated that bottlenose

dolphins remove bait and catch from handlines used to catch bottomfish off the island of Hawai'i and Ka'ula Rock and on several banks of the NWHI. Fishermen have reported that interactions with dolphins that steal bait and catch are increasing. Interaction rates between dolphins and the NWHI bottomfish fishery have been estimated based on studies conducted in 1990-1993, indicating that an average of 2.67 dolphin interactions, most likely involving bottlenose and rough-toothed dolphins (*Steno bredanensis*), occurred for every 1000 fish brought on board (Kobayashi and Kawamoto 1995). It is not known whether these interactions result in serious injury or mortality of dolphins. Beginning in the early 1970s the National Marine Fisheries Service received reports of fishermen shooting at bottlenose dolphins to deter them from taking fish catches (Nitta and Henderson 1993). Nitta and Henderson (1993) also reported that one bottlenose dolphin calf was removed from a small-mesh set gillnet off Maui in 1991 and expressed surprise that bottlenose dolphins are "rarely reported entangled or raiding set gill nets in Hawaii," considering that they so often remove fish from fishing lines. In Hawai'i, some mortality of bottlenose dolphins has been observed in inshore gillnets (including an entangled dolphin that stranded in 1998: Carretta et al. 2004), but no estimate of annual human-caused mortality and serious injury is available for this stock, because these fisheries are not observed or monitored.

No habitat issues are known to be of concern for bottlenose dolphins. They are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA.

Sustained swim speeds for bottlenose dolphins range between 4 and 20 km/h (2.2 and 10.8 knots). Speeds commonly range from 6.4 to 11.5 km/h (3.4 to 6.2 knots) and may reach speeds as high as 29.9 km/h (16.1 knots) for 7.5 seconds (Croll et al., 1999). Dive times range from 38 seconds to 1.2 min but have been known to last as long as 10 min (Mate et al. 1995); Croll et al. 1999). The dive depth of a bottlenose dolphin in Tampa Bay was measured at 98 m (322 ft) (Mate et al. 1995). The deepest dive recorded for a bottlenose dolphin is 535 m (1,755 ft), reached by a trained individual (Ridgway, 1986).

At present, there is very little information about the prey species or feeding behavior of the bottlenose dolphins off the island of Hawai'i, although studies in other parts of the world have found bottlenose dolphins to be very opportunistic in their feeding behavior (see review in Connor et al. 2000). The diet of the bottlenose dolphin is diverse in nature, ranging from coastal squid and fish to small mesopelagic fish and squid (Croll et al., 1999), with a preference for sciaenids, scombrids, and mugilids (Wells and Scott, 2002). Seasonal and geographical variation may influence the diet of bottlenose dolphins (Evans, 1994). There is also some evidence that dolphins feed in different areas depending on sex and size. Lactating females and calves have been reported foraging in the near-shore zone, while adolescents feed farther offshore. Females without young and male adults may feed still farther offshore (Wells and Scott, 2002). Bottlenose dolphins appear to be active during both the day and night. Their activities are influenced by the seasons, time of day, tidal state, and physiological factors such as reproductive seasonality (Wells and Scott, 2002).

Bottlenose dolphins hear underwater sounds in the range of 150 Hz to 135 kHz (Johnson, 1967; Ljungblad et al., 1982). Their best underwater hearing occurs at 15 kHz, where the threshold level range is 42 to 52 dB RL (Sauerland and Dehnhardt, 1998). Bottlenose dolphins also have good sound location abilities and are most sensitive when sounds arrive from the front (Richardson et al., 1995).

Bottlenose dolphins produce sounds as low as 0.05 kHz and as high as 150 kHz with dominant frequencies at 0.3 to 14.5 kHz, 25 to 30 kHz, and 95 to 130 kHz (Johnson, 1967; Popper, 1980a; McCowan and Reiss, 1995; Schultz et al., 1995; Croll et al., 1999; Oswald et al., 2003). The maximum SL is 228 dB re 1 µPa at 1 m (P-P) (Croll et al., 1999). Bottlenose dolphins produce a variety of whistles, echolocation clicks and burst-pulse sounds. Echolocation clicks with peak frequencies from 40 to 130 kHz are hypothesized to be used in navigation, foraging, and predator detection (Au, 1993; Houser et al., 1999 *in* Helweg et al., 2003; Jones and Sayigh, 2002). According to Au (1993), biosonar clicks are broadband, ranging in frequency from a few kHz to more than 150 kHz, with a 3-dB bandwidth of 30 to 60 kHz (Croll et al., 1999). The echolocation signals usually have a 50 to 100 microsecond duration with peak frequencies ranging from 30 to 100 kHz and fractional bandwidths between 10 and 90 percent of the peak frequency (Houser et al., 1999 *in* Helweg et al., 2003).

Burst-pulses, or squawks, are commonly produced during social interactions. These sounds are broadband vocalizations that consist of rapid sequences of clicks with inter-click intervals less than 5 milliseconds. Burst-pulse sounds are typically used during escalations of aggression.

Each individual bottlenose dolphin has a fixed, unique FM pattern, or contour whistle called a signature whistle. These signal types have been well studied and are presumably used for recognition, but may have other social contexts (Frankel, 2002; Sayigh, 2002). More recent work with synthetically produced signature whistles has demonstrated that the whistle contour itself conveys information to the listener (Janik et al. 2006). This is a necessary condition for the animals to use the signature whistles in a referential, or labeling, context. One application of this may be seen as bottlenose dolphins appear to be use signature whistles as a contact call when animals are separated (Watwood et al. 2005). Signature whistles typically have a narrow-band sound with the frequency commonly between 4 and 20 kHz, duration between 0.1 and 3.6 seconds, and a SL of 125 to 140 dB re 1 µPa at 1m (Caldwell et al. 1990).

Cuvier's Beaked Whale (*Ziphius cavirostris*):

Estimating the abundance and density of beaked whales is more difficult than for most other cetacean species, because beaked whales spend so much of their time submerged and field identification is difficult (Barlow et al. 2006). Cuvier's beaked whales occur in all oceans and major seas (Heyning 1989). In Hawai'i, five strandings have been reported from Midway Atoll, Pearl & Hermes Reef, O'ahu, and the island of Hawai'i (Shallenberger 1981; Galbreath 1963; Richards 1952; Nitta 1991; Maldini et al. 2005). Sightings have been reported off Lana'i and Maui (Shallenberger 1981) and Hawai'i, Ni'ihau, and Kaua'i (Mobley et al. 2000; Baird et al. 2004). Three sightings were made during a 2002 shipboard survey of waters within the U.S. EEZ of the Hawaiian Islands (Barlow 2006). While nothing is known about stock structure, some genetic samples have been collected recently (Carretta et al. 2004), and photo-

identification studies have suggested long-term sight fidelity for the west side of the island of Hawai'i (McSweeney et al. 2007). In U.S. Pacific EEZ, the following three stocks are recognized for management purposes under the MMPA: 1) Hawaiian, 2) Alaskan, and 3) California, Oregon and Washington.

In Hawaiian waters, nothing is known about the stock structure of this species. Wade and Gerrodette (1993) made an abundance estimate of Cuvier's beaked whales in the ETP of 20,000 (CV = 0.265), but it is not known if these are part of the Hawaiian stock. The Hawaiian stock was estimated at 43 (CV=0.51) animals based on twelve aerial surveys conducted in 1993, 1995 and 1998 (Mobley et al. 2000). This abundance underestimates the total number of Cuvier's beaked whales within the U.S. EEZ off Hawai'i, because areas around the NWHI and beyond 25 nmi from the main Hawaiian Islands were not surveyed (Carretta et al. 2004). Furthermore, this species is known to spend a large proportion of time diving, causing additional downward bias in the abundance estimate. A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 15,242 (CV=1.43) Cuvier's beaked whales (Barlow 2006), including a correction factor for missed diving animals. This is currently the best available abundance estimate for this stock.

Cuvier's beaked whales are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA.

No Cuvier's beaked whales were observed hooked or entangled in the Hawai'i-based longline fishery in U.S. and international waters between 1994 and 2002, with approximately 4-25% of all effort observed (Forney 2004). However, three unidentified cetaceans, which may have been Cuvier's beaked whales, were taken in this fishery (Forney 2004). The increasing levels of anthropogenic noise in the world's oceans has been suggested to be a habitat concern for whales (Richardson et al. 1995), particularly for deep-diving whales like Cuvier's beaked whales that feed in the oceans' "sound channel" (Carretta et al. 2004). In recent years, there has been increasing concern that loud underwater sounds, such as active sonar and seismic operations, may be harmful to beaked whales (Malakoff 2002). The use of active sonar from military vessels has been implicated in mass strandings of beaked whales in the Mediterranean Sea during 1996 (Frantzis 1998), the Bahamas during 2000 (Carretta et al. 2004), and the Canary Islands 2002 (Martel 2002). Similar military active sonar operations may occur around the Hawaiian Islands but are unlikely near Honokohau Bay.

Swim speeds of Cuvier's beaked whale have been recorded between 5 and 6 km/h (2.7 and 3.3 knots) (Houston, 1991). Dive durations range between 20 and 87 min with an average dive time near 30 min (Heyning, 1989; Jefferson et al., 1993; (Baird et al. 2004). Dive depths for this species are inconclusive. Cuvier's beaked whales consume squid and deep-sea fish (Clarke 1996).

There is no direct measurement of auditory threshold for the hearing sensitivity of Cuvier's beaked whales (Ketten, 2000; (Thewissen 2002). Studies on Cuvier's beaked whales and Blainville's beaked whales conducted by Johnson et al. (2004) concluded that no vocalizations were detected from any tagged beaked whales when they were within 200 m (656.2 ft) of the surface. The Cuvier's beaked whale started clicking at an average depth of 475 m (1,558.4 ft), ranging from 450 to 525 m (1,476 to 1,722 ft), and stopped clicking when they started their ascent at an average depth of 850 m (2,789 ft), with a range of 770 to 1,150 m (2,526 to 3,773 ft). The intervals between regular clicks were approximately 0.4 second. Trains of clicks often end in a rapid increase in the click rate, which is also called a buzz. According to these studies, both the Cuvier's beaked whale and the Blainville's beaked whale have a somewhat flat spectrum that was accurately sampled by Johnson et al. (2004) between 30 and 48 kHz. There may be a slight decrease in the spectrum above 40 kHz, but the 96 kHz sampling rate was not sufficient to sample the full frequency range of clicks from either of the species (Johnson et al., 2004). Beaked whales are capable of producing SLs of 200 to 220 dB (peak-to-peak) (Johnson et al., 2004).

Zimmer et al. (2005a) also studied Cuvier's beaked whales and their echolocation clicks. The highest measured SL was 214 dB (peak-to-peak). It is recognized in this study that it is possible that Cuvier's beaked whales cannot produce any higher source levels, but it is more likely that the full capabilities of the Cuvier's beaked whales are underestimated by this study. Therefore, the maximum SL shown in this study may be the result of the whale's reducing the volume when ensonifying at each other (Zimmer et al., 2005a).

Dwarf Sperm Whale (*Kogia sima*):

Dwarf sperm whales, like pygmy sperm whales, are found in tropical to warm-temperate waters worldwide (Nagorsen 1985). At least four strandings of dwarf sperm whales have been documented in Hawai'i (Tomich 1986; Nitta 1991; Maldini et al. 2005). Two sightings of five pygmy or dwarf sperm whales were made between Hawai'i and Maui during twelve aerial surveys conducted in 1993, 1995 and 1998 within about 25 nmi of the main Hawaiian Islands (Mobley et al. 2000). Five sightings of dwarf sperm whale were made during a 2002 shipboard survey of waters within the U.S. EEZ of the Hawaiian Islands (Barlow 2006). Baird (2005b) reports that dwarf sperm whales are the sixth most commonly sighted odontocete around the main Hawaiian Islands. High site fidelity has been suggested off the west side of the island of Hawai'i, evidenced by a high rate of both within- and between-year photographic re-sightings (Baird et al. 2006b). In U.S. Pacific EEZ, the following two stocks are recognized for management purposes under the MMPA: 1) Hawaiian, and 2) California, Oregon and Washington.

A conservative estimate of approximately 11,200 was made for dwarf sperm whales in the ETP (Wade and Gerrodette 1993), Pacific, but it is not known whether these animals are part of the same population that occurs in the central North Pacific (Carretta et al. 2004). A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 17,519 (CV=0.74) dwarf sperm whales (Barlow 2006), including a correction factor for missed diving animals. This is currently the best available abundance estimate for this stock.

No estimate of annual human-caused mortality is available for the Hawaiian stock of dwarf sperm whales because no reports of direct or incidental takes have been reported in Hawaiian waters (Nitta and Henderson 1993). None were observed hooked in the Hawai'i-based longline fishery between 1994 and 2002, with approximately 4-25% of all effort observed (Forney 2004).

Dwarf sperm whales are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA. The increasing levels of anthropogenic noise in the world's oceans has been suggested to be a habitat concern for whales (Richardson et al. 1995), particularly for deep-diving whales like dwarf sperm whales that feed in the oceans' "sound channel" (Carretta et al. 2004).

A stranded *Kogia breviceps* produced ultrasonic clicks, with frequencies between 60 and 200 kHz with a peak in energy at 125 kHz (Marten 2000). Click duration averaged 600 µsec, and repetition rates began typically began at 20 Hz and increased during a click train. Kogia simus has been reported to have clicks between 13 and 33 kHz (Jérémie et al. 2006), however the details of the recording equipment were not provided. Therefore, the completeness of this report remains in doubt.

False Killer Whale (*Pseudorca crassidens*):

False killer whales are found in tropical and warm-temperate waters worldwide (Stacey et al. 1994). In the North Pacific this species is well known from southern Japan, Hawai'i and the ETP. In U.S. Pacific waters, one stock of false killer whales, the Hawaiian stock, is recognized for management purposes under the MMPA. Fishery interactions with false killer whales demonstrate that this species also occurs in U.S. EEZ waters around Palmyra Atoll (Carretta et al. 2004) but it is not known whether these animals are part of the Hawaiian stock or whether they represent a separate stock of false killer whales. False killer whales occur around all the main Hawaiian Islands (Nitta and Henderson 1993) as well as the NWHI (Barlow 2003b). There are six stranding records from Hawaiian waters (Nitta 1991; Maldini et al. 2005). Two sightings of false killer whales were made during a 2002 shipboard survey of waters within the U.S. EEZ of the Hawaiian Islands (Barlow 2006). While there is apparently inter-island movement of false killer whales, at least within the leeward Hawaiian Islands (Baird et al. 2005a), genetic analyses of tissue samples collected near the main Hawaiian Islands indicate that Hawaiian false killer whales are reproductively isolated from false killer whales found in the eastern tropical Pacific Ocean (Chivers et al. In Press).

Population estimates for this species have been made for Japanese waters (16,600 animals, Miyashita 1993) and the ETP (39,800 animals, CV = 0.636, Wade and Gerrodette 1993). However, evidence suggests these animals are from different populations (Carretta et al. 2004). Aerial surveys were flown within 25nmi of the main Hawaiian Islands in 1993, 1995 and 1998 and resulted in an abundance estimate of 121 (CV=0.47) false killer whales for this stock (Mobley et al. 2000). This is an underestimate of abundance because the survey did not encompass their entire range in Hawaiian waters and estimates were uncorrected for the proportion of diving animals missed from the survey aircraft (Carretta et al. 2004). A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 236 (CV=1.13) false killer whales (Barlow 2006). This is the best available abundance estimate for false killer whales within the Hawaiian Islands EEZ.

False killer whales have been identified in fishermen's logs and NOAA Fisheries observer records as taking catches from pelagic longlines (Nitta and Henderson 1993; Carretta et al. 2004). They have also been observed feeding on mahimahi (*Coryphaena* *hippurus*) and yellowfin tuna (*Thunnus albacares*) and frequently steal large fish (up to 70 pounds) (Shallenberger 1981) from the trolling lines of both commercial and recreational fishermen (Carretta et al. 2004). Between 1994 and 2002, at least ten false killer whales were observed hooked in the Hawai'i-based longline fishery with approximately 4-25% of all effort observed (Forney 2004). Baird and Gorgone (2005) examined the rate of major dorsal fin disfigurements of false killer whales from near-shore waters around the main Hawaiian Islands and hypothesized that these animals were likely part of the same population that interacts with the Hawai'i-based tuna and swordfish longline fishery in offshore Hawaiian waters.

False killer whales are not listed as "depleted" under the MMPA nor as "threatened" or "endangered" under the ESA. Because the rate of mortality and serious injury to false killer whales within the Hawaiian Islands EEZ in the Hawai'i-based longline fishery (4.4 animals per year) exceeds the Potential Biological Removal (PBR) level (1.0) (Carretta et al. 2004), this stock is considered a strategic stock under the MMPA.

False killer whales have an approximate swim speed of 3 km/h (1.6 knots), although a maximum swim speed has been documented as 28.8 km/h (11.9 knots) (Brown et al. 1966; Rohr et al., 2002). No data is available on diving (Baird 2002a). Their diet consists primarily of fish and squid and on occasion, other small odontocetes (Evans and Raga, 2001; Baird, 2002a).

False killer whales hear underwater sounds in the range of <1 to 115 kHz (Johnson, 1967; Awbrey et al., 1988; Au, 1993). Their best underwater hearing occurs at 17 kHz, where the threshold level ranges between 39 to 49 dB RL (Sauerland and Dehnhardt, 1998).

Au et al. (1997) conducted a survey on the effects of the Acoustic Thermometry of Ocean Climate (ATOC) program on false killer whales and on Risso's dolphins. The ATOC program broadcast a low-frequency 75-Hz phase modulated, 195 dB SL signal through ocean basin-sized water masses to study ocean temperatures on a global scale. The hearing sensitivity was measured for false killer whales. The hearing thresholds for false killer whales were 140.7 dB RL, plus or minus 1.2 dB for the 75-Hz pure tone signal and 139.0 dB RL plus or minus 1.1 dB for the ATOC signal.

False killer whales produce a wide variety of sounds from 4 to 130 kHz, with dominant frequencies between 25 to 30 kHz and 95 to 130 kHz (Busnel and Dziedzic, 1968; Kamminga and van Velden, 1987; Thomas and Turl, 1990; Murray et al., 1998). Most signal types vary between whistles, burst-pulse sounds and click trains (Murray et al. 1998). Whistles generally range between 5.4 and 8.3 kHz (Rendell et al. 1999). False killer whales echolocate highly directional clicks ranging between 20 and 60 kHz and 100 and 130 kHz (Kamminga and van Velden, 1987; Thomas and Turl, 1990). There is no available data regarding seasonal or geographical variation in the sound production of false killer whales. Estimated SL of clicks are near 228 dB re 1 µPa at 1m (P-P) (Thomas and Turl, 1990).

Fraser's Dolphin (*Lagenodelphis hosei*):

Little is known about Fraser's dolphin, which is a tropical oceanic species distributed worldwide (Perrin et al. 1994a; Jefferson and Leatherwood 1994). It has only recently been documented within the U.S. EEZ of the Hawaiian Islands, during a 2002 cetacean survey (Barlow 2006). One stranding from the island of Kaua'i has since been documented in 2004 (M. Breese, pers. comm.). For the MMPA stock assessment reports, there is a single Pacific management stock including only animals found within the U.S. EEZ of the Hawaiian Islands.

An estimate of abundance for this species in the ETP was made of 289,300 Fraser's dolphins (CV = 0.335) (Wade and Gerrodette 1993), but it is not known whether these animals are part of the same population that occurs around the Hawaiian Islands and in the central North Pacific (Carretta et al. 2004). No sightings of this species were made during twelve aerial surveys conducted in 1993, 1995 and 1998 within about 25 nmi of the main Hawaiian Islands (Mobley et al. 2000). A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 10,226 (CV=1.16) Fraser's dolphins (Barlow 2006). This is currently the best available abundance estimate for this stock.

Fraser's dolphins are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA.

Swim speeds of Fraser's dolphin have been recorded between 4 and 7 km/h (2.2 and 3.8 knots) with swim speeds up to 28 km/hr (15 knots) when escaping predators (Croll et al., 1999). Several foraging depths have been recorded. Based on prey composition, it is believed that Fraser's dolphins feed at two depth horizons in the eastern tropical Pacific. The shallowest depth in this region is no less than 250 m (820 ft) and the deepest is no less than 500 m (1640 ft). In the Sulu Sea, they appear to feed near the surface to at least 600 m (1968.5 ft) In South Africa and in the Caribbean, they were observed feeding near the surface (Dolar et al. 2003). According to Watkins et al. (1994), Fraser's dolphins herd when they feed, swimming rapidly to an area, diving for 15 seconds or more, surfacing and splashing in a coordinated effort to surround the school of fish. Dive durations are not available. They feed on mesopelagic fish, crustaceans, and cephalopods, particularly Myctophidae, Chauliodontidae, and Oplophoridae (Croll et al., 1999; Dolar, 2002).

There is no direct measurement of auditory threshold for the hearing sensitivity of Fraser's dolphins (Ketten, 2000; Thewissen, 2002).

Fraser's dolphins produce sounds ranging from 4.3 to over 40 kHz (Leatherwood et al., 1993; Watkins et al., 1994). Echolocation clicks are described as short broadband sounds without emphasis at frequencies below 40 kHz, while whistles were frequency-modulated tones concentrated between 4.3 and 24 kHz. Whistles have been suggested as communicative signals during social activity (Watkins et al., 1994).

Killer Whale (*Orcinus orca*):

Killer whales have been observed in all oceans and seas throughout the world (Leatherwood and Dahlheim 1978). Although reported from tropical and offshore waters (Heyning and Dahlheim 1988), killer whales prefer the colder waters of both hemispheres, with greatest abundances found within 800 km of major continents (Mitchell 1975). They are rare in Hawaiian waters (Baird et al. 2006a), and no data are available to estimate abundance for this species in the central Pacific (Carretta et al. 2004). No killer whales were seen during 1993-98 aerial surveys within about 25 nmi of the main Hawaiian Islands, but one sighting was reported during subsequent surveys (Mobley et al. 2000, 2001). Two sightings of killer whales were made during a 2002 shipboard survey of waters within the U.S. EEZ of the Hawaiian Islands (Barlow 2006). One stranding from the island of Hawai'i was reported in 1950 (Richards 1952) and another from the island of Lana'i in 2004 (M. Breese, pers. comm.). Except in the northeastern Pacific where "resident", "transient", and "offshore" stocks have been described for coastal waters of Alaska, British Columbia, and Washington to California (Bigg 1982; Leatherwood et al. 1990; Bigg et al. 1990; Ford et al. 1994), little is known about stock structure of killer whales in the North Pacific.

Baird et al. (2006a) reviewed 21 records of killer whales around the main Hawaiian Islands between 1994 and 2004 (with one sighting off French Frigate Shoals in the Northwestern Hawaiian Islands). Group sizes reported from these Hawaiian sightings ranged from 1 to 10 individuals, with a mean group size of 4.2 (SD 1/4 2.1). Baird et al (2006) also note analyses of skin samples from two animals indicated two mitochondrial haplotypes, one identical to the ''Gulf of Alaska transient 2'' haplotype (a mammal-eating form), and the other a unique mitochondrial haplotype for Hawaiian killer whales. Based on this and external morphology, they speculate that there may be genetic differentiation from populations from the coastal temperate waters of western North America.

In the Pacific U.S. EEZ, the following five stocks of killer whales are recognized for management purposes under the MMPA: 1) the Eastern North Pacific Northern Resident stock - occurring from British Columbia through Alaska, 2) the Eastern North Pacific Southern Resident stock - occurring within the inland waters of Washington State and southern British Columbia, 3) the Eastern North Pacific Transient stock - occurring from Alaska through California, 4) the Eastern North Pacific Offshore stock - occurring from Southeast Alaska through California, and 5) the Hawaiian stock (Carretta et al. 2004).

For the ETP, Wade and Gerrodette (1993) estimated the killer whale population to be 8,500 animals (CV = 0.368) from shipboard sightings surveys. Population sizes for killer whales in the coastal waters of British Columbia and Washington were estimated from photo-identification studies to be 261 animals (Bigg et al. 1990). The 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 349 (CV=0.98) killer whales (Barlow 2006). This is currently the best available abundance estimate for this stock.

Threats to killer whales in this stock are difficult to quantify due to limited data. In 1990, a solitary killer whale was reported to have removed the catch from a longline in Hawai'i (Dollar 1991). None were observed hooked or entangled in the Hawai'i-based longline fishery between 1994 and 2002, with approximately 4-25% of all effort observed (Forney 2004). This species is not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA. Because they feed at higher trophic levels, transient

killer whales may be more susceptible to bioaccumulation of environmental contaminants such as organochlorines (Ylitalo et al. 2001; Herman et al. 2005).

Swimming speeds usually range between 6 to 10 km/h (3.2 to 5.4 knots), but they can achieve speeds up to 37 km/h (20 knots) in short bursts (Lang, 1966; (LeDuc 2002). In southern British Columbia and northwestern Washington State, killer whales spend 70 percent of their time in the upper 20 m (66 ft) of the water column, but can dive to 100 m (330 ft) or more with a maximum-recorded depth of 201 m (660 ft) (Baird et al., 1998). The deepest dive recorded by a killer whale is 265 m (870 ft), reached by a trained individual (Ridgway, 1986). Dive durations recorded range from 1 to 10 min (Norris and Prescott, 1961; Lenfant, 1969; Baird et al., 1998).

Killer whales have perhaps the most diverse food habits of any marine mammal, feeding on a variety of fish species, cephalopods, pinnipeds, sea otters, whales, dolphins, seabirds, and marine turtles (Hoyt, 1981; Gaskin, 1982; Jefferson et al., 1991). In the Bering Sea there is some suggestion that killer whales prey on fish at water depths of 200 to 300 m (660-990 ft) or more (Yano and Dahlheim, 1995a and b). In Hawai'i, evidence of a diversity of prey types (including cephalopods, humpback whales, and possibly other cetaceans) suggests that killer whales in Hawaiian waters may not specialize only on marine mammals as seen in some temperate populations of killer whales in the North Pacific (Baird et al. 2006)

Killer whales hear underwater sounds in the range of <500 Hz to 120 kHz (Bain et al., 1993; Szymanski et al 1999). Their best underwater hearing occurs between 15 and 42 kHz, where the threshold level is near 34 to 36 dB RL (Hall and Johnson, 1972; Szymanski et al 1999).

Killer whales produce sounds as low as 80 Hz and as high as 85 kHz with dominant frequencies at 1-20 kHz (Schevill and Watkins, 1966; Diercks et al., 1971, 1973; Evans, 1973; Steiner et al., 1979; Awbrey et al., 1982; Ford and Fisher, 1983; Ford, 1989; Miller and Bain, 2000). An average of 12 different call types (range 7 to 17), mostly repetitive discrete calls, exist for each pod (Ford, 2002). Pulsed calls and whistles, called dialects, carry information hypothesized as geographic origin, individual identity, pod membership, and activity level. Vocalizations tend to be in the range between 500 Hz and 10 kHz and may be used for group cohesion and identity (Ford, 2002; Frankel, 2002). Whistles and echolocation clicks are also included in killer whale repertoires, but are not a dominant signal type of the vocal repertoire in comparison to pulsed calls (Miller and Bain, 2000). Nevertheless, a comparison of tonal (FM) whistles from the four acoustic clans off British Columbia found that the separated northern and southern residents had clearly different calls. The three southern clans that geographically overlap have identical calls (Riesch et al. 2006). These tonal calls may help provide community level recognition. Erbe (2002) recorded received broadband sound pressure levels of orca burst-pulse calls ranging between 105 and 124 dB re 1 μPa at an estimated distance of 100 m.

Longman's Beaked Whale (*Indopacetus pacificus*):

Estimating the abundance and density of beaked whales is more difficult than for most other cetacean species, because beaked whales spend so much of their time submerged and field identification is difficult (Barlow et al. 2006). Longman's beaked whale is considered one of the rarest and least known cetacean species (Jefferson et al. 1993; Rice 1998; Dalebout et al. 2003). The distribution of Longman's beaked whale, as determined from stranded specimens and sighting records of 'tropical bottlenose whales', includes tropical waters from the eastern Pacific westward through the Indian Ocean to the eastern coast of Africa. No strandings of Longman's beaked whales have been documented in Hawaiian waters, although numerous strandings of unidentified beaked whales have been reported (Nitta 1991; Maldini et al. 2005). One sighting of Longman's beaked whale was made during a 2002 survey of waters within the U.S. Exclusive Economic Zone (EEZ) of the Hawaiian Islands (Barlow 2006). For management purposes under MMPA, there is one Pacific stock of Longman's beaked whales, found within waters of the Hawaiian Islands EEZ.

A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 1,007 (CV=1.26) Longman's beaked whales (Barlow 2006). This is currently the best available abundance estimate for this stock.

In recent years, there has been increasing concern that loud underwater sounds, such as active sonar and seismic operations, may be harmful to deep-diving beaked whales (Malakoff 2002). The use of active sonar from military vessels has been implicated in mass strandings of beaked whales in the Mediterranean Sea during 1996 (Frantzis 1998), the Bahamas during 2000 (Carretta et al. 2004), and the Canary Islands 2002 (Martel 2002). Similar military active sonar operations may occur around the Hawaiian Islands but are unlikely near Honokohau Bay.

Longman's beaked whales are not listed as "threatened" or "endangered" under the ESA nor as "depleted" under the MMPA.

Longman's beaked whales in the western Indian ocean appear to have bimodal dive times; with short dives lasting between 11 to 18 minutes while longer dives last from 20 to 33 minutes (Anderson et al. 2006). Most of the whales seen in the Indian ocean were associated with the slope region, in waters from 250 to 2,500 m (Anderson et al. 2006).

Melon-headed Whale (*Peponocephala electra*):

Relatively little is known about melon-headed whales, which are distributed in tropical to warm-temperate waters worldwide (Perryman et al. 1994). They frequently eat small schooling fish, but also feed on squid (Sekiguchi et al. 1992; Jefferson and Barros 1997). These whales prefer deep, equatorial ocean waters (Watkins et al. 1997) and are thought to feed deep in the water column because one of their primary prey, mesopelagic squid, are found in waters up to 1,500m (4,920ft) deep (Jefferson and Barros 1997).

Median melon-headed whale group size around the main Hawaiian Islands from boat-based surveys was 305 individuals, with a range from 17 to 800 animals (Huggins et al. 2005). Large groups are seen regularly off all the main Hawaiian Islands (Shallenberger 1981; Baird et al. 2003; Huggins et al. 2005) over a range of water depths

(255 to 4,407m), but most frequently in depths greater than 2,000m (Huggins et al. 2005). Shallenberger (1981) described them as especially frequent off the Waianae coast of O'ahu, the north Kohala coast of Hawai'i, and the leeward coast of Lana'i. In Hawai'i, melon-headed whales are known to interact with humpback whales, rough-toothed dolphins, pantropical spotted dolphins (Huggins et al. 2005), short-finned pilot whales (Migura and Meadows 2002) and have been observed avoiding killer whales (Huggins et al. 2005). Inter-island movements from Kaua'i to Hawai'i have been documented based on photo-identified individuals (Huggins et al. 2005).

A comprehensive shipboard survey of the Hawaiian EEZ resulted in only one sighting of melon-headed whales (Barlow 2006). Little is known about this species elsewhere in its range, and most knowledge about its biology comes from mass strandings (Perryman et al. 1994). Eighteen strandings are known from Hawai'i (Nishiwaki and Norris 1966; Shallenberger 1981; Nitta 1991; Maldini et al. 2005; Southall et al. 2006). For management purposes under the MMPA, there is a single Pacific stock of melon-headed whales including only animals found in the U.S. EEZ of the Hawaiian Islands (Carretta et al. 2004).

Wade and Gerrodette (1993) produced an estimate of 45,400 melon-headed whales (CV = 0.467) in the ETP based on 14 sightings made during vessel surveys between1986 and 1990, but it is not known whether any of these animals are part of the same population that occurs around the Hawaiian Islands. Abundance of the Hawaiian stock was estimated as 154 (CV=0.88) animals based on aerial surveys conducted in 1993, 1995 and 1998 around the main Hawaiian Islands (Mobley et al. 2000). This study underestimated the total number of melon-headed whales within the U.S. EEZ off Hawai'i, because areas around the NWHI and beyond 25 nautical miles from the main islands were not surveyed (Carretta et al. 2004). A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 2,950 (CV=1.17) melon-headed whales (Barlow 2006). This is currently the best available abundance estimate for this stock.

Melon-headed whales are not known to be taken by any fisheries in Hawaiian waters (Nitta and Henderson 1993). None were observed hooked in the Hawai'i-based longline fishery between 1994 and 2002, with approximately 4-25% of all effort observed (Forney 2004). On July 3-4, 2004, a stranding event occurred in which 150 to 200 melon–headed whales occupied the shallow waters of Hanalei Bay, Kaua'i, Hawai'i for over 28 hours. Investigations concluded that active Naval sonar transmissions were a plausible, if not likely, contributing factor in what may have been a confluence of events (Southall et al. 2006).

Melon-headed whales are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA.

General swim speeds for this melon-headed whales are not available. No data is available on dive depths and dive times of melon-headed whales. Melon-headed whales feed on mesopelagic squid found down to 1,500 m (4,920 ft) deep, so they appear to feed deep in the water column (Jefferson and Barros, 1997).

There is no direct measurement of auditory threshold for the hearing sensitivity of melon-headed whales (Ketten, 2000; (Thewissen 2002).

Melon-headed whales produce sounds between 8 and 40 kHz. Individual click bursts have frequency emphases between 20 and 40 kHz. Dominant frequencies of whistles are 8-12 kHz, with both upsweeps and downsweeps in frequency modulation (Watkins et al., 1997). There are no available data regarding seasonal or geographical variation in the sound production of this species. Maximum SLs are estimated at 155 dB for whistles and 165 dB for click bursts (Watkins et al., 1997).

Pantropical Spotted Dolphin (*Stenella attenuata*):

Pantropical spotted dolphins are primarily found in tropical and subtropical waters worldwide (Perrin and Hohn 1994). This species is found in both nearshore and oceanic waters (Reeves and Leatherwood 1994). Much of what is known about the species in the North Pacific has been learned from specimens obtained in the large directed fishery in Japan and in the eastern tropical Pacific (ETP) tuna purse-seine fishery (Perrin and Hohn 1994). These dolphins are common and abundant throughout the Hawaiian archipelago, particularly in channels between islands, over offshore banks (e.g. Penguin Banks), and off the lee shores of the islands (Shallenberger 1981; Barlow 2006). Östman-Lind et al. (2004) calculated a preliminary rough minimum abundance estimate of approximately 250 pantropical spotted dolphins utilizing the near-shore waters off the western coast of the Island of Hawai'i. They also noted the presence of near-shore mixed-species aggregations of spinner (*S. longirostris*) and pantropical spotted dolphins off this same coast. Twelve strandings of this species have been documented in Hawai'i (Nitta 1991; Maldini et al. 2005). Morphological differences and distribution patterns have been used to establish that the spotted dolphins around Hawai'i belong to a stock that is distinct from those in the ETP (Perrin 1975; Dizon et al. 1994; Perrin et al. 1994b). Their possible affinities with other stocks elsewhere in the Pacific are unknown. Fishery interactions with pantropical spotted dolphins demonstrate that this species also occurs in U.S. EEZ waters around Palmyra Island (Carretta et al. 2004), but these animals may represent a separate stock of pantropical spotted dolphins.

For the MMPA stock assessment reports, there is a single Pacific management stock including only animals found within the U.S. EEZ of the Hawaiian Islands. Spotted dolphins involved in eastern tropical Pacific tuna purse-seine fisheries are managed separately under the MMPA.

An abundance estimate of 2,928 (CV=0.45) pantropical spotted dolphins in Hawai'i was calculated from aerial surveys flown in 1993, 1995 and 1998 (Mobley et al. 2000). This number is an underestimate because areas around the Northwestern Hawaiian Islands and beyond 25 nautical miles from the main islands were not surveyed (Carretta et al. 2004). A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 8,978 (CV=0.48) pantropical spotted dolphins (Barlow 2006). This is currently the best available abundance estimate for this stock of pantropical spotted dolphins.

Previous to 1994 there were no reports of direct or incidental takes of this species in Hawaiian waters (Nitta and Henderson 1993). Between 1994 and 2002 one pantropical spotted dolphin was observed entangled and killed in the Hawai'i-based

longline fishery within U.S. EEZ waters, with approximately 4-25% of all effort observed (Forney 2004).

Spotted dolphins are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA.

Pantropical spotted dolphins have been documented to feed during the day (e.g. Östman-Lind et al. 2004), but it has also been suggested that they move inshore to feed on the mesopelagic boundary community during the night (Baird et al. 2001), like spinner dolphin schools.

Pantropical spotted dolphins have been recorded swimming up to 39.7 km/hr (21.4 knots) for 2 seconds, although, this may be an overestimate. Other individuals have been recorded as swimming at speeds of 4 to 19 km/hr (2.2 to 10.3 knots) with bursts up to 22 km/hr 12 knots) (Perrin, 2002d). Pantropical spotted dolphins off Hawai'i have been recorded to dive at a maximum depth of 122 m (400 ft) during the day and 213 m (700 ft) during the night (Baird et al. 2001). The average dive duration for the pantropical spotted dolphins is 1.95 min with depths as deep as 100 m (Scott et al., 1993). Dives of up to 3.4 min have been recorded (Perrin, 2002d). An Atlantic spotted dolphin was documented with a maximum dive duration of 3.5 min (Davis et al. 1996).

Atlantic spotted dolphins produce a variety of sounds, including whistles, whistle-squawks, buzzes, burst-pulses, synch pulses, barks, screams, squawks, tail slaps, and echolocation clicks. Like other odontocetes, they produce broadband, short duration echolocation signals. Most of these signals have a bimodal frequency distribution. They project relatively high-amplitude signals with a maximum SL of about 223 dB (Au and Herzing, 2003). Their broadband clicks have peak frequencies between 60 and 120 kHz. Dolphins produce whistles with frequencies generally in the human audible range, below 20 kHz. These whistles often have harmonics which occur at integer multiples of the fundamental and extend beyond the range of human hearing. Atlantic spotted dolphins have also been recorded making burst pulse squeals and squawks, along with bi-modal echolocation clicks with a low-frequency peak between 40 and 50 kHz and a high-frequency peak between 110 and 130 kHz. Many of the vocalizations from Atlantic spotted dolphins have been associated with foraging behavior (Herzing, 1996). There is no available data regarding seasonal variation in the sound production of *Stenella* dolphins, although geographic variation is evident. Peak-to-peak SLs as high as 210 dB have been measured (Au et al., 1998; Au and Herzing, 2003). Pantropical spotted dolphins whistles have a mean minimum frequency of 8.2 (S.D. = 1.7) kHz and a mean upper frequency of 18.7 (SD = 3.0) kHz. The mean duration of these whistles was 0.9 seconds (SD = 0.4) (Oswald et al. 2003). These pantropical spotted dolphin data are consistent with those of the better-described Atlantic spotted dolphin.

Pygmy Killer Whale (*Feresa attenuata*):

The pygmy killer whale is widely distributed in tropical and subtropical waters worldwide (Ross and Leatherwood 1994). They are poorly known in most parts of their range (Carretta et al. 2004). Most knowledge of this species is from stranded or live-captured specimens. Pryor et al. (1965) stated that pygmy killer whales have been observed several times off the lee shore of O'ahu, and that "they seem to be regular residents of the Hawaiian area." Although all sightings up to that time had been off

O'ahu and the Big Island, Shallenberger (1981) stated that this species might be found elsewhere in Hawai'i, as well. No pygmy killer whales were seen during 1993-98 aerial surveys within about 25 nmi of the main Hawaiian Islands (Mobley et al. 2000). Three sightings of pygmy killer whales were made during a 2002 shipboard survey of U.S. EEZ waters surrounding the Hawaiian Islands (Barlow 2006). Six strandings have been documented from Maui and the island of Hawai'i (Nitta 1991; Maldini et al. 2005). For management purposes under the MMPA, one stock of this species is recognized in the U.S. Pacific waters and it is the Hawaiian stock.

A population estimate has been made for this species in the eastern tropical Pacific (Wade and Gerrodette 1993), but it is not known whether any of these animals are part of the same population that occurs around the Hawaiian Islands. The 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 956 (CV=0.83) pygmy killer whales (Barlow 2006). This is currently the best available abundance estimate for this stock. Results of a 19-year photo-identification study off the island of Hawai'i suggest that the population size in this area is small (likely 100-200 individuals), and the individuals show a very high level of site fidelity (McSweeney et al. 2005).

Pygmy killer whales are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA.

General swim speeds for this species is not available. No dive data are available. Pygmy killer whales feed on cephalopods and small fish (Donahue and Perryman, 2002). They are also suspected of feeding on small marine mammals (Evans and Raga, 2001).

There is no direct measurement of auditory threshold for the hearing sensitivity of pygmy killer whales (Ketten, 2000(Thewissen 2002). Little is known of the sound production of this species. One document describes pygmy killer whales producing LF "growl" sounds (Pryor et al., 1965). Echolocation clicks are short (25µs) with estimated source levels between 197 and 223 dB re 1µPa at 1m (P-P) (Madsen et al. 2004b). The spectrum of these clicks were bimodal, with peaks at 45 and 117 kHz, although the received spectral is aspect-dependent.

Pygmy Sperm Whale (*Kogia breviceps*):

The pygmy sperm whale, like the dwarf sperm whale, is found in tropical to warm-temperate waters worldwide (Caldwell and Caldwell 1989). Between the years 1949 and 2002, at least 22 strandings of this species were reported in the Hawaiian Islands (Tomich 1986; Nitta 1991; Maldini et al. 2005). A stranded calf was held for several days at Sea Life Park (Pryor 1975). Shallenberger (1981) reported three sightings off O'ahu and Maui. Two sightings of pygmy or dwarf sperm whales were made between Hawai'i and Maui during 1993-98 aerial surveys within about 25 nmi of the main Hawaiian Islands (Mobley et al. 2000). Two sightings were made during a 2002 shipboard survey of waters within the U.S. EEZ of the Hawaiian Islands (Barlow 2006). Baird (2005b) reported one sighting off Ni'ihau and another off the island off Hawai'i (Carretta et al. 2004). Nothing is known about stock structure for this species. For management purposes under the MMPA, two stocks of pygmy sperm whales are

recognized in U.S. waters of the Pacific Ocean: 1) Hawaiian and 2) California, Oregon, Washington.

A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 7,138 (CV=1.12) pygmy sperm whales (Barlow 2006), including a correction factor for missed diving animals. This is currently the best available abundance estimate for this stock.

Little is known about pygmy sperm whale interactions with fisheries, but no direct or incidental takes have been documented for all Hawaiian pelagic fisheries (e.g. Nitta and Henderson 1993) and none were observed hooked or entangled in the Hawai'i-based longline fishery between 1994 and 2002, with approximately 4-25% of all effort observed (Forney 2004).

Pygmy sperm whales are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA. The increasing levels of anthropogenic noise in the world's oceans has been suggested to be a habitat concern for whales (Richardson et al. 1995), particularly for deep-diving whales like pygmy sperm whales that feed in the oceans' "sound channel".

Swim speeds of pygmy sperm whales vary and were found to reach up to 11 km/h (5.9 knots) (Scott et al. 2001). In the Gulf of California, *Kogia* species have been recorded with an average dive time of 8.6 min and a maximum dive time of 43 min for dwarf sperm whales in the Gulf of Mexico (Breese and Tershy, 1993; Willis and Baird, 1998). *Kogia* spp. consume a variety of cephalopod species and occasionally feed on fish and crustaceans (McAlpine 2002).

There are sparse data on the hearing sensitivity for pygmy sperm whales. An Auditory Brainstem Response study on a rehabilitating pygmy sperm whale indicated that this species has an underwater hearing range that is most sensitive between 90 and 150 kHz (Carder et al., 1995; (Ridgway and Carder 2001).

Recent recordings from captive pygmy sperm whales indicate that they produce sounds between 60 and 200 kHz with peak frequencies at 120-130 kHz (Santoro et al., 1989; Carder et al., 1995; (Ridgway and Carder 2001). Echolocation pulses were documented with peak frequencies at 125 to 130 kHz (Ridgway and Carder 2001). Thomas et al. (1990) recorded a LF sweep between 1,300 and 1,500 Hz from a captive pygmy sperm whale in Hawai'i. Richardson et al. (1995) reported pygmy sperm whale frequency ranges for clicks to be between 60 and 200 kHz with the dominant frequency at 120 kHz. No geographical or seasonal differences in sounds have been documented. Estimated source levels were not available.

Risso's Dolphin (*Grampus griseus*):

Risso's dolphins are distributed worldwide in temperate and tropical waters (Kruse et al. 1999). They have been considered rare in Hawaiian waters (Shallenberger 1981). Only one sighting was made during aerial surveys in 1993, 1995 and 1998 (Mobley et al. 2000). However, seven sightings were made during a 2002 survey of the U.S. EEZ of the Hawaiian Islands (Barlow 2006). There are five stranding records from the main islands (Nitta 1991; Maldini et al. 2005). For management purposes under the

MMPA, there are two stocks of Risso's dolphins recognized within the Pacific U.S. EEZ: 1) Hawaiian, and 2) California, Oregon and Washington (Carretta et al. 2004).

An abundance estimate of 16,483 Risso's dolphins (CV = 0.28) was produced for waters of California, Oregon and Washington waters, from a weighted 1991-96 average based on three ship surveys (Barlow 1997). Population estimates have also been made off Japan (Miyashita 1993) and in the eastern tropical Pacific (Wade and Gerrodette 1993), but it is not known whether these animals are part of the same population that occurs around the Hawaiian Islands and in the central North Pacific. A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 2,372 (CV=0.65) Risso's dolphins (Barlow 2006). This is currently the best available abundance estimate for this stock.

Interactions with cetaceans have been reported for all Hawaiian pelagic fisheries (Nitta and Henderson 1993), and some of these interactions involved Risso's dolphins. Between 1994 and 2002, seven Risso's dolphins were observed hooked or entangled in the Hawai'i-based longline fishery outside of U.S. EEZ waters, with approximately 4-25% of all effort observed (Forney 2004). During the 905 observed trips with 11,014 sets, the average interaction rate of Risso's dolphins was one animal per 129 fishing trips, or one animal per 1,573 sets. All Risso's dolphins caught were considered seriously injured (Forney 2004), based on an evaluation of the observer's description of the interaction and following established guidelines for assessing serious injury in marine mammals (Angliss and Demaster 1998). Risso's dolphins are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA.

Swim speeds from Risso's dolphins were recorded at 2 to 12 km/h (1.1 to 6.5 knots) off Santa Catalina Island (Shane, 1995). Risso's dolphins feed on squid species found more than 400 m (1,300 ft) deep (Gonzalez et al., 1994 *in* Croll et al., 1999). Behavioral research suggests that Risso's dolphins primarily feed at night (Baird 2002b). There are currently no known studies on diving behavior.

Audiograms for Risso's dolphins indicate their hearing RLs equal to or less than approximately 125 dB in frequencies ranging from 1.6 to 110 kHz (Nachtigall et al, 1995 *in* Nedwell et al., 2004). Phillips et al. (2003) report that Risso's dolphins are capable of hearing frequencies up to 80 kHz. Best underwater hearing occurs between 4 and 80 kHz with hearing threshold levels from 63.6 to 74.3 dB RL. Hearing thresholds from this study were tested between 1.6 and 110 kHz and were approximately 125 dB down to approximately 65 dB RL (Nachtigall et al., 1995 *in* Croll et al., 1999 and Nedwell et al., 2004). Other audiograms obtained on Risso's dolphin (Au et al., 1997) confirm previous measurements and demonstrate hearing thresholds of 140 dB RL for a one-second 75 Hz signal (Au et al., 1997; Croll et al., 1999).

The hearing sensitivity was measured for Risso's dolphins and their thresholds were found to be 142.2 dB RL, plus or minus 1.7 dB for the 75-Hz pure tone signal and 140.8 dB RL plus or minus 1.1 dB for the ATOC signal (Au et al., 1997). The ATOC signal was a low-frequency 75-Hz phase modulated signal, with a source level of 195 dB re 1 µPa at 1m.

Risso's dolphins produce sounds as low as 30 Hz and as high as 150 kHz (Corkeron and Van Parijs 2001; Madsen et al. 2004a). Their dominant frequencies are

between at 2 to 5 kHz and at 65 kHz. (Watkins, 1967; Au, 1993; Croll et al., 1999; Phillips et al., 2003). In one experiment conducted by Phillips et al. (2003), clicks were found to have a peak frequency of 65 kHz, with 3-dB bandwidths at 72 kHz and durations ranging from 40 to 100 microsecond. In a second experiment, Phillips et al. (2003) recorded clicks with peak frequencies up to 50 kHz, 3-dB bandwidth at 35 kHz with durations ranging from 35 to 75 microsecond. SLs were up to 208 dB. The behavioral and acoustical results from these experiments provided evidence that Risso's dolphins use echolocation. Estimated SLs of echolocation clicks can reach up to 216 dB (Phillips et al., 2003). Recordings of a wild animal produced similar measurements of clicks. These were short (40 µs), broadband clicks with peak frequencies around 50 kHz and source levels between 202 and 222 dB re. 1 µPa at 1m (P-P) (Madsen et al. 2004a). Other sounds include "bark" vocalizations consisted of highly variable burst pulses and have a frequency range of 2 to 20 kHz. Buzzes consisted of a short burst pulse of sound around 2 seconds in duration with a frequency range of 2.1 to 22 kHz. LF, narrowband grunt vocalizations ranged between 400 and 800 Hz. Chirp vocalizations were slightly higher in frequency than the grunt vocalizations, ranging in frequency from 2 to 4 kHz. There are no available data regarding seasonal or geographical variation in the sound production of Risso's dolphin.

Rough-toothed Dolphin (*Steno bredanensis*):

The rough-toothed dolphin is found in tropical and warm-temperate seas worldwide (Miyazaki and Perrin 1994). They are present around all the main Hawaiian Islands (Shallenberger 1981; Tomich 1986) and have been observed at least as far northwest as French Frigate Shoals (Barlow 2006; Nitta and Henderson 1993). Eight strandings have been reported from Maui, O'ahu, and the island of Hawai'i (Nitta 1991; Maldini et al. 2005). Nothing is known about stock structure for this species in the North Pacific. Photographic identification studies around the main Hawaiian Islands suggest little or no inter-island movement of this species (Webster et al. 2005). For management purposes under the MMPA, there is a single Pacific management stock including only animals found within the U.S. EEZ of the Hawaiian Islands.

Wade and Gerrodette (1993) produced an abundance estimate of 145,900 rough-toothed dolphins (CV = 0.320) from five ship surveys conducted each year between 1986 and 1990 in the ETP, but it is not known whether these animals are part of the same population that occurs around the Hawaiian Islands. An abundance estimate of 123 Hawaiian rough-toothed dolphin (CV=0.63) was made based on aerial surveys flown in 1993, 1995, and 1998 (Mobley et al. 2000). This study underestimated the total number of rough-toothed dolphins within the U.S. EEZ off Hawai'i, because areas around the NWHI and beyond 25 nautical miles from the main islands were not surveyed (Carretta et al. 2004). A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 8,709 (CV=0.45) rough-toothed dolphins (Barlow 2006). This is currently the best available abundance estimate for this stock.

Interactions with cetaceans have been reported for all Hawaiian pelagic fisheries, and some of these interactions involved rough-toothed dolphins (Nitta and Henderson 1993). They have been observed apparently preying on adult-sized mahimahi

(*Coryphaena hippurus*) in Hawai'i and are known to take bait and catch from Hawaiian sport and commercial fisheries operating near the main islands and in a portion of the northwestern islands (Shallenberger 1981; Schlais 1984; Nitta and Henderson 1993; Pitman and Stinchcomb 2002). They have been specifically reported to interact with the day hand-line fishery for tuna (palu-ahi) and the troll fishery for billfish and tuna (Schlais 1984; Nitta and Henderson 1993). Interaction rates between dolphins and the NWHI bottomfish fishery have been estimated based on studies conducted in 1990-1993, indicating that an average of 2.67 dolphin interactions, most likely involving bottlenose and rough-toothed dolphins, occurred for every 1000 fish brought on board (Kobayashi and Kawamoto 1995). Fishermen report interactions with dolphins, which steal bait and catch are increasing (Carretta et al. 2004). It is not known whether these interactions result in serious injury or mortality of dolphins. There has been an apparent decline in the frequency of sightings of rough-toothed dolphins off the island of Hawai'i over the last 20 years (Baird et al. 2003) and it has been suggested that this decline may be associated with shooting of animals in the areas where fishery interactions have been documented (Baird et al. 2003). They are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA.

Rough-toothed dolphins are not known to be fast swimmers. They are known to skim the surface at a moderate speed and have a distinctive splash (Jefferson, 2002c). Swim speeds of this species vary from greater than 5.5 to 16 km/h (3.0 to 8.6 knots). Rough-toothed dolphins can dive down between 30 and 70 m (98 and 230 ft)(Croll et al., 1999). The dive duration ranges from 0.5 to 3.5 min (Ritter 2002). The maximum dive recorded was 70 m (230 ft). Although, due to their morphology, it is believed that they are capable of diving much deeper. Dives up to 15 min have been recorded for groups of dolphins (Croll et al., 1999).

There is no direct measurement of auditory threshold for the hearing sensitivity of rough-toothed dolphins (Ketten, 2000; Thewissen, 2002).

Rough-toothed dolphins produce sounds ranging from 0.1 kHz up to 200 kHz (Popper, 1980a; Miyazaki and Perrin, 1994; Richardson et al., 1995). Clicks have peak energy at 25 kHz, while whistles have a maximum energy between 2 to 14 kHz and at 4 to 7 kHz (Norris and Evans, 1967; Norris, 1969; Popper, 1980a). There is no available data regarding seasonal or geographical variation in the sound production of this species.

Short-finned Pilot Whale (*Globicephala macrorhynchus*):

Short-finned pilot whales occur in tropical and warm temperate waters worldwide. In the North Pacific Ocean their distribution extends into cool temperate waters. They are commonly observed around the main Hawaiian Islands and are also present around the NWHI (Shallenberger 1981; Barlow 2006). During a 2002 shipboard survey of waters within the U.S. EEZ of the Hawaiian Islands, 25 sightings of short-finned pilot whales were made (Barlow 2006). Fourteen strandings of short-finned pilot whales have been documented from the main Hawaiian Islands, including five mass strandings (Tomich 1986; Nitta 1991; Maldini et al. 2005). In the North Pacific, stocks for this species are not well defined, except off Japan where two morphologically distinct allopatric stocks occur (Kasuya et al. 1988). Preliminary photo-identification work with

pilot whales in Hawai'i indicated a high degree of site fidelity around the main island of Hawai'i (Shane and McSweeney 1990). Genetic analyses of tissue samples collected near the main Hawaiian Islands indicate that Hawaiian short-finned pilot whales are reproductively isolated from short-finned pilot whales found in the eastern Pacific Ocean (Chivers et al. 2003), however, the offshore range of this Hawaiian population is unknown. Fishery interactions with short-finned pilot whales demonstrate that this species also occurs in U.S. EEZ waters of Palmyra Island, but it is possible that these animals represent a separate stock (Carretta et al. 2004). For management purposes under the MMPA, short-finned pilot whales within the Pacific U.S. EEZ are divided into two discrete stocks: 1) Hawaiian, and 2) California, Oregon and Washington.

Estimates of short-finned pilot whale populations have been made off Japan (Miyashita 1993) and in the eastern tropical Pacific (Wade and Gerrodette 1993), but it is not known whether any of these animals are part of the same population that occurs around the Hawaiian Islands. Aerial surveys were flown within 25 nmi of the main Hawaiian Islands in 1993, 1995 and 1998 and resulted in an abundance estimate of 1,708 (CV=0.32) short-finned pilot whales (Mobley et al. 2001). This study underestimated the total number of short-finned pilot whales within the U.S. EEZ off Hawai'i, because areas around the NWHI and beyond 25 nautical miles from the main islands were not surveyed (Carretta et al. 2004). A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 8,870 (CV=0.38) short-finned pilot whales (Barlow 2006). This is currently the best available abundance estimate for short-finned pilot whales within the Hawaiian Islands EEZ.

Between 1994 and 2002, five short-finned pilot whales were observed hooked in the Hawai'i-based longline fishery with approximately 4-25% of all effort observed (Forney 2004). During the 905 observed trips with 11,014 sets, the average interaction rate of short-finned pilot whales was one animal per 181 fishing trips, or one animal per 2,203 sets. Two of the animals caught were dead upon gear retrieval, and two additional animals were considered seriously injured (Forney 2004), based on an evaluation of the observer's description of the interaction and following established guidelines for assessing serious injury in marine mammals (Angliss and DeMaster 1998). Average 5-yr estimates of annual mortality and serious injury for 1998-2002 are 4.2 (CV = 0.78) short-finned pilot whales outside of the U.S. EEZs, and 0.8 (CV = 1.00) within the U.S. EEZ of Palmyra Island. No short-finned pilot whales were observed taken within the Hawaiian Islands EEZ during 1998-2002. Short-finned pilot whales with propeller scars have been seen around the Hawaiian Islands, but it is unknown if any of these injuries were serious or resulted in mortalities (Carretta et al. 2004).

Short-finned pilot whales are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA.

Pilot whales generally have swim speeds ranging between 2 to 12 km/h (1.1 to 6.5 knots) (Shane 1995). Long-finned pilot whales have an average speed of 3.3 km/h (1.8 knots) (Nelson and Lien, 1996). Short-finned pilot whales have swim speeds ranging between 7 and 9 km/h (3.8 and 4.6 knots) (Norris and Prescott, 1961).

Both long- and short-finned pilot whales are considered deep divers, feeding primarily on fish and squid (Croll et al., 1999). Long-finned pilot whales range in dive depths from 16 m (52 ft) during the day to 648 m (2126 ft) during the night (Baird et al. 2002). The dive times varied between 2 and 13 min. A short-finned pilot whale was recorded as diving to 610 m (2,000 ft) (Ridgway, 1986).

There is no direct measurement of auditory threshold for the hearing sensitivity of either long- or short-finned pilot whales (Ketten, 2000; (Thewissen 2002).

Pilot whales echolocate with a precision similar to bottlenose dolphins and also vocalize with other school members (Olson and Reilly, 2002). Short-finned pilot whales produce sounds as low as 280 Hz and as high as 100 kHz, with dominant frequencies between 2 to 14 kHz and 30 to 60 kHz (Caldwell and Caldwell, 1969; Fish and Turl, 1976; Scheer et al., 1998). Sounds produced by this species average near 7,870 Hz, higher than that of a long-finned pilot whale (Olson and Reilly, 2002). Echolocation abilities have been demonstrated during click production (Evans, 1973). SLs of clicks have been measured as high as 180 dB (Fish and Turl 1976; Richardson et al., 1995). There are little available data regarding seasonal or geographical variation in the sound production of the short-finned pilot whale, although there is evidence of group specific call repertoires (Olson and Reilly, 2002).

Sperm Whale (*Physeter macrocephalus*):

There is much uncertainty surrounding the identity and status of sperm whale populations. Sperm whales are widely distributed in deep waters across the entire North Pacific and into the southern Bering Sea in summer but the majority are thought to be south of 40°N in winter (Rice 1974, 1989; Gosho et al. 1984; Miyashita et al. 1995). For management, the International Whaling Commission (IWC) had divided the North Pacific into two management regions, but has not reviewed this stock boundary in many years (Donovan 1991). The Hawaiian Islands marked the center of a major nineteenth century whaling ground for sperm whales (Gilmore 1959; Townsend 1935). Since 1936, at least 18 strandings have been reported from O'ahu, Kaua'i and Kure Atoll (Woodward 1972; Nitta 1991; Maldini et al. 2005). Sperm whales have also been sighted around several of the NWHI (Rice 1960; Barlow 2006), off the main island of Hawai'i (Lee 1993; Mobley et al. 2000) in the Kaua'i Channel and in the Alenuihaha Channel between Maui and the island of Hawai'i (Shallenberger 1981). In addition, the sounds of sperm whales have been recorded throughout the year off O'ahu (Thompson and Friedl 1982). A summer/fall 2002 shipboard survey of waters within the U.S. EEZ of the Hawaiian Islands resulted in 43 sperm whale sightings throughout the study area (Barlow 2006).

There is much uncertainty surrounding the stock identity of sperm whales in the North Pacific. A 1997 survey designed specifically to investigate stock structure and abundance of sperm whales in the northeastern temperate Pacific revealed no apparent hiatus in distribution between the U.S. EEZ off California and areas farther west, out to Hawai'i (Carretta et al. 2004). Very preliminary genetic analyses revealed significant differences between sperm whales off the coast of California, Oregon and Washington and those sampled offshore to Hawai'i (Carretta et al. 2004). For management purposes under the MMPA, three stocks of sperm whales are recognized within the Pacific U.S. EEZ: 1) Hawaiian, 2) California, Oregon and Washington, and 3) Alaskan.

A spring 1997 combined visual and acoustic line-transect survey conducted in the eastern temperate North Pacific resulted in estimates of 24,000 (CV=0.46) sperm whales based on visual sightings, and 39,200 (CV=0.60) based on acoustic detections and visual group size estimates (Carretta et al. 2004). In the eastern tropical Pacific, the abundance of sperm whales has been estimated as 22,700 (95% C.I.=14,800-34,600, Wade and Gerrodette 1993). However, it is not known whether any or all of these animals routinely enter the U.S. EEZ of the Hawaiian Islands. Aerial surveys were flown within 25 nmi of the main Hawaiian Islands in 1993, 1995 and 1998 and resulted in an average abundance estimate of 66 (CV=0.56) sperm whales (Mobley et al. 2000). This is an underestimate of abundance within the Hawaiian EEZ because areas around the NWHI and beyond 25 nautical miles from the main islands were not surveyed (Carretta et al. 2004). Furthermore, this species is known to spend a large proportion of time diving, causing additional downward bias in the abundance estimate (Carretta et al. 2004). A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 6,919 (CV=0.81) sperm whales (Barlow 2006), including a correction factor for missed diving animals. This is currently the best available abundance estimate for this stock.

Interactions with cetaceans are reported for all pelagic fisheries, and large whales have been entangled in longlines off the Hawaiian Islands (Nitta and Henderson 1993; Carretta et al. 2004). Between 1994 and 2002, one sperm whale was observed entangled within the Hawaiian Islands EEZ in the Hawai'i-based longline fishery, with approximately 4-25% of all effort observed (Forney 2004). During the 905 observed trips with 11,014 sets, the average interaction rate of sperm whales was one animal per 905 fishing trips, or one animal per 11,014 sets. The caught animal was apparently able to free itself and was not considered seriously injured (Forney 2004), following established guidelines for assessing serious injury in marine mammals (Angliss and DeMaster 1998). One additional sperm whale was observed taken in an experimental set outside the U.S. EEZ, but the severity of its injuries could not be determined (Forney 2004). Sperm whales have been documented to depredate longlines in the Gulf of Alaska offshore of southeastern Alaska (Straley et al. 2005).

Sperm whales are formally listed as "endangered" under the ESA and, consequently, the Hawaiian stock is automatically considered as a "depleted" and "strategic" stock under the MMPA. The increasing levels of anthropogenic noise in the world's oceans has been suggested to be a habitat concern for whales (Richardson et al. 1995), particularly for deep-diving whales like sperm whales that feed in the oceans' "sound channel".

Swim speeds of sperm whales range from 1.25 to about 4 km/h (0.7 to 2.2 knots) (Jaquet et al. 2000); (Whitehead 2002). Dive durations range between 18.2 to 65.3 min (Watkins et al. 2002). Sperm whales may be the longest and deepest diving mammals, having been recorded diving for over 2 hours to depths of 3,000 m (9,842 ft) (Clarke 1976); (Watkins et al. 1985). Foraging dives typically last about 30 to 40 min and descend to depths from 300 to 1,245 m (984 to 4,085 ft) (Papastavrou et al. 1989); (WAHLBERG 2002). Sperm whales mostly feed on squid, but also include demersal and mesopelagic fish in their diet, although, their feeding habits are region-specific (e.g., Iceland) (Reeves and Whitehead 1997); (Whitehead 2002).

Recent audiograms measured from a sperm whale calf resulted in an auditory range of 2.5 to 60 kHz, best hearing sensitivity between 5 and 20 kHz (Ridgway and Carder, 2001). Measurements of evoked response data from one stranded sperm whale have shown a lower limit of hearing near 100 Hz (Gordon et al., 1996).

Sperm whales produce broadband clicks with energy from less than 100 Hz to 30 kHz (Watkins and Schevill, 1977; Watkins et al., 1985; (Goold and Jones 1995); (Weilgart and Whitehead 1997); (Mohl et al. 2000); (MADSEN et al. 2002); (Thode et al. 2002). Regular click trains and creaks have been recorded from foraging sperm whales and may be produced as a function of echolocation (Whitehead and Weilgart 1991); (Jaquet et al. 2001); (Madsen et al. 2002). A series of short clicks, termed "codas," have been associated with social interactions and are thought to play a role in communication (Watkins and Schevill 1977)Weilgart and Whitehead, 1993; (Pavan et al. 2000). Distinctive coda repertoires have shown evidence of geographical variation among female sperm whales (Weilgart and Whitehead 1997); (Whitehead 2002). SELs of clicks have been measured between 202 and 236 dB (Madsen and Møhl 2000; Mohl et al. 2000; Mohl et al. 2003); (Thode et al. 2002).

Spinner Dolphin (*Stenella longirostris*):

Spinner dolphins are found around the world in tropical and warm-temperate waters (Perrin and Gilpatrick 1994). They are common and abundant throughout the entire Hawaiian archipelago (Shallenberger 1981; Andrews et al. 2006; Karczmarski et al. 2005; Norris and Dohl 1980; Norris et al. 1994), where groups enter the nearshore, bay, or lagoon shallows daily to rest and socialize, returning to deeper offshore waters at night to forage. It is believed that relatively shallow, sandy-bottom areas, serve as rest habitat, likely providing increased protection against predation from large sharks (Norris 1994). Twenty-six strandings have been reported in Hawai'i (Maldini et al. 2005). Recent studies have revealed that, with few exceptions, dolphins at different Hawaiian Islands throughout the chain are significantly genetically differentiated from dolphins at every other island (Andrews et al. 2006). Exceptions were dolphins at Kure Atoll, Midway Atoll, and Pearl & Hermes Reef, which together seemed to form one interbreeding group, distinct from the rest of the archipelago. This suggestion is bolstered by photo-identification data, which documented movement of animals from Midway Atoll to Kure Atoll and from Pearl & Hermes Reef to Midway Atoll (Rickards et al. 2002).

Furthermore, there appears to be a well-pronounced differentiation in the population structure and social dynamics of spinner dolphins across the Hawaiian island chain (Karczmarski et al. 2005). There is some suggestion from photo-identification studies off the Kona Coast of Hawai'i that the waters surrounding this island may have a large, relatively stable "resident" population (Norris et al. 1994; Östman-Lind et al. 2004).

Hawaiian spinner dolphins belong to a stock that is separate from those involved in the tuna purse-seine fishery in the eastern tropical Pacific (Dizon et al. 1994). Most spinner dolphin stocks, including the Hawaiian spinner dolphin, are of the subspecies Gray's spinner dolphin (*Stenella longirostris longirostris*), which occurs pantropically

(Perrin 1990). For management purposes under the MMPA, there is a single Pacific management stock including only animals found within the U.S. EEZ of the Hawaiian Islands. Spinner dolphins involved in eastern tropical Pacific tuna purse-seine fisheries are managed separately under the MMPA (Carretta et al. 2004).

In Hawai'i spinner dolphins feed nocturnally on mesopelagic fishes, shrimp and squid (e.g. *Abralia trigonura*, Clarke and Young 1998) in association with the diel vertical and horizontal (Benoit-Bird et al. 2001) migration of the mesopelagic-boundary community (Norris and Dohl 1980; Würsig et al. 1994; Benoit-Bird and Au 2001). The mesopelagic-boundary community is a distinct land-associated assemblage of mesopelagic micronekton, which exists around the Hawaiian Islands (Reid et al. 1991).

Twelve aerial surveys were conducted within about 25 nmi of the main Hawaiian Islands in 1993, 1995 and 1998 and an abundance estimate of 3,184 (CV=0.37) spinner dolphins was calculated from the combined survey data (Mobley et al. 2000). This study underestimated the total number of spinner dolphins within the U.S. EEZ off Hawai'i, because areas around the NWHI and beyond 25 nautical miles from the main islands were not surveyed (Carretta et al. 2004). A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 3,351 (CV=0.74) spinner dolphins (Barlow 2006). This is currently the best available abundance estimate for this stock, but it may be negatively biased because relatively little survey effort occurred in nearshore areas where these dolphins are abundant. Rough abundance estimates for animals along the Kona coast of the Island of Hawai'i, based on photo-identification data, have varied from 960 animals in 1979-80 (Norris et al. 1994) to 2,334 in 1989-1992 (Östman 1994) to 855 in 2003 (Östman-Lind et al. 2004). Östman-Lind et al. (2004) also noted the presence of near-shore mixed-species aggregations of spinner and pantropical spotted dolphins off this same coast.

In Hawai'i, some entanglements of spinner dolphins have been observed (Nitta and Henderson 1993; Rickards et al. 2001; Carretta et al. 2004; HMMC, unpublished data), but no estimate of annual human-caused mortality and serious injury is available, because the nearshore gillnet fisheries are not observed or monitored (Carretta et al. 2004). Interactions with cetaceans have been reported for all Hawaiian pelagic fisheries (Nitta and Henderson 1993). Between 1994 and 2002, two spinner dolphins were observed hooked or entangled in the Hawai'i-based longline fishery, with approximately 4-25% of all effort observed (Forney 2004). Neither of the animals caught was considered seriously injured (Forney 2004), based on an evaluation of the observer's description of the interaction and following established guidelines for assessing serious injury in marine mammals (Angliss and Demaster 1998). A habitat issue of increasing concern is the potential effect of swim-with-dolphin programs and other tourism activities on spinner dolphins around the main Hawaiian Islands (Carretta et al. 2004, Östman-Lind et al. 2004).

Spinner dolphins are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA.

Hawaiian spinner dolphins have swim speeds ranging from 2.6 to 6 km/h (1.4 to 3.2 knots) (Norris et al., 1994). The hourly average speeds of a spinner dolphin in the Eastern Tropical Pacific, accompanying a spotted dolphin, ranged from 2.33 to 10.71 kts

(Leatherwood and Ljungblad 1979), considerably higher than the speed reported by Norris et al (1994)

Spinner dolphins produce burst pulse calls, echolocation clicks, whistles and screams (Norris et al., 1994; Bazua-Duran and Au, 2002). The results of a study on spotted and spinner dolphins conducted by Lammers et al. (2003) revealed that the whistles and burst pulses of the two species span a broader frequency range than is traditionally reported for delphinids. The fundamental frequency contours of whistles occur in the human hearing range, but the harmonics typically reach 50 kHz and beyond. Additionally, the burst pulse signals are predominantly ultrasonic, often with little or no energy below 20 kHz (Lammers et al., 2003).

Striped Dolphin (*Stenella coeruleoalba*):

Striped dolphins are found in tropical and warm-temperate pelagic waters worldwide (Perrin et al. 1994c). While sightings have historically been infrequent (Shallenberger 1981; Mobley et al. 2000), they have been documented in the Hawaiian Islands from 20 strandings (Nitta 1991; Maldini et al. 2005). A comprehensive shipboard survey of the Hawaiian EEZ resulted in 15 sightings of striped dolphins (Barlow 2006). Striped dolphins have been intensively exploited in the western North Pacific, where three migratory stocks are provisionally recognized (Kishiro and Kasuya 1993). In the eastern Pacific all striped dolphins are provisionally considered to belong to a single stock (Dizon et al. 1994). Within the Pacific U.S. EEZ, the following two stocks of striped dolphins are recognized for management purposes under the MMPA: 1) California, Oregon and Washington, and 2) Hawai'i. Striped dolphins involved in eastern tropical Pacific tuna purse-seine fisheries are managed separately under the MMPA (Carretta et al. 2004).

Population estimates are available for striped dolphins in Japanese waters (Miyashita 1993) and the eastern tropical Pacific (Wade and Gerrodette 1993), but it is not known whether any of these animals are part of the Hawaiian stock. Aerial surveys of the main Hawaiian Islands conducted in 1993, 1995 and 1998 resulted in an abundance estimate of 114 (CV=1.19) spinner dolphins (Mobley et al. 2000). This is an underestimate of spinner dolphins in the Hawaiian EEZ because areas around the NWHI and beyond 25 nautical miles from the main islands were not surveyed (Carretta et al. 2004). A 2002 shipboard line-transect survey of the entire Hawaiian Islands EEZ resulted in an abundance estimate of 13,143 (CV=0.46) striped dolphins (Barlow 2006). This is currently the best available abundance estimate for this stock.

Striped dolphins are not listed as "threatened" or "endangered" under the ESA, nor as "depleted" under the MMPA.

Based on Auditory Brainstem Responses, striped dolphins hear SLs equal to or louder than 120 dB in the range of less than 10 to greater than 100 kHz (Popper, 1980a). The behavioral audiogram developed by Kastelein et al. (2003) shows hearing capabilities from 0.5 to 160 kHz. The best underwater hearing of the species appears to be at from 29 to 123 kHz (Kastelein et al. 2003). They have relatively less hearing sensitivity below 32 kHz and above 120 kHz.

The results of a study on spotted and spinner dolphins conducted by Lammers et al. (2003) revealed that the whistles and burst pulses of the two species span a broader frequency range than is traditionally reported for delphinids. The fundamental frequency contours of whistles occur in the human hearing range, but the harmonics typically reach 50 kHz and beyond. Additionally, the burst pulse signals are predominantly ultrasonic, often with little or no energy below 20 kHz (Lammers et al., 2003).

3.0 PINNIPEDS

Hawaiian monk seal (*Monachus schauinslandi*):

The worldwide population size for monk seals was estimated at nearly 1,400 in 2000 (Reeves et al., 2002). In Hawai'i, monk seals are found almost exclusively on the northwest Hawaiian Islands, where they occasionally move among islands and atolls. Their rookeries are primarily located on the Leeward Islands of French Frigate Shoals, Pearl and Hermes Reef, Kure Atoll, and Laysan and Lisianski Islands (Croll et al., 1999; Reeves et al., 2002). Smaller colonies also live on Nihoa and Necker Islands. After two males were translocated to Johnston Atoll in 1997, a few seals have been seen there each year. Hawaiian monk seals have also been seen in the main islands of Hawai'i and since the 1980s, pups have been born on the islands of Maui, Kaua'i, O'ahu, and Moloka'i. Hawaiian monk seals do not seem to be tolerant of human presence. When the U.S. military inhabited Sand Island and the Midway Islands and Kure Atoll, the monk seals disappeared until after the military left. Monk seals prefer to be solitary animals (Reeves et al., 2002).

Hawaiian monk seals are listed as "endangered" under the ESA and IUCN, and protected under CITES.

Mean descent and ascent speeds from tagged monk seal pups were 0.6 and 0.4 m/s (2.2 and 1.5 km/h), respectively (Gazo et al. 2006). Individual juvenile seals had mean velocities as high as 1.55 and 1.34 m/s (5.6 and 4.8 km/h). Since these velocities were based on change in depth over time, they are likely underestimates, as the seals probably dove and surface at an angle (instead of perfectly vertically). The highest swimming speed allowed in an analysis of satellite tag data was 7.2 km/h (Parrish and Abernathy 2006). Foraging dive durations last up to 4 min in the pups. Adult monk seals regularly dive to at least 500 m (the limit of the depth recorder in that study) and these dives can last 20 minutes (Parrish et al. 2002). Some dives have been recorded to last longer than 30 min; however, it is unclear if these are foraging dives. Hawaiian monk seals forage on benthic or reef fish, cephalopods, and crustaceans (particularly lobster).

Underwater hearing in the Hawaiian monk seal has been measured between 300 Hz to 40 kHz. Their most sensitive hearing is at 12 to 28 kHz, which is a narrower range compared to other phocids. Above 30 kHz, their hearing sensitivity drops markedly (Thomas et al. 1990). No underwater sound production has been reported. The in-air vocalizations of a female after giving birth included "low-pitched moans or guttural growls" (Eliason et al. 1990).The pup emitted an "abrupt bleat". Both of these calls had their fundamental frequency between 100 and 200 Hz, indicating the potential for good low-frequency hearing. Other in air sounds include a soft liquid bubble (100 to 400 Hz), a guttural expiration (<800 Hz), a roar (<800 Hz), and a belch cough (Miller and Job, 1992).

4.0 ANIMAL DENSITY

Several sources were examined to provide estimates of marine mammal density in Hawaiian waters. Aerial surveys were conducted over the time period of 1993-1998 and resulted in density estimates for odontocetes (Mobley et al. 2000). Additional aerial surveys were conducted and these data used to produce density estimates for humpback whales (Mobley 2004). The data were segregated by year, and the 2000 estimate was the highest. The 2003 estimate was lower, which may be due to an anomalous year or an anomalous sampling for that year. Since the population is known to be increasing at a rate of ~9% per year, the highest density value was used. Not all species were observed during aerial surveys. Therefore shipboard survey data was also examined. The HICEAS survey produced abundance and density estimates for the Hawaiian Islands (Barlow 2006). This study reported abundance for the main Hawaiian Islands. These abundance numbers were converted to densities by dividing the number of individuals by the area of the study (212,892 sq km). The study itself calculated density values based on both the Main Hawaiian Islands and the 200 nmi Exclusive Economic Zone (EEZ). Since the study area is nearshore off the Big Island, the data from only the main Hawaiian Islands are presented when available. Some species were not seen in the main Hawaiian Islands during this study and the overall densities are reported for them. These are indicated by the Heavy outlined boxes in the Barlow column in Table 2. Finally, several species are 'grayed out', as they are very unlikely to ever be in the vicinity of Honokohau harbor. The deep-diving species are not excluded, as deep water is in close proximity to Honokohau harbor. They are unlikely to be nearby, but it remains a possibility.

		Mobley Data			Barlow Data	
Common name	**Scientific name**	Density	CV (%)		Density	CV (%)
Blainville's beaked whale	*Mesoplodon densirostris*	0.0009	59.6		0.00117	125
Blue whale	*Balaenoptera musculus*					
Bottlenose dolphin	*Tursiops truncatus*	0.0103	55.7		0.00131	59
Bryde's whale	*Balaenoptera edeni*				0.00019	45
Cuvier's beaked whale	*Ziphius cavirostris*	0.0006	51.2		0.00621	143
Dwarf sperm whale	*Kogia sima*				0.00714	74
False killer whale	*Pseudorca crassidens*				0.00010	113
Fin whale	*Balaenoptera physalus*					
Fraser's dolphin	*Lagenodelphis hosei*				0.00417	116
Humpback whale	*Megaptera novaeangliae*	0.2694	15.2			
Killer whale	*Orcinus orca*				0.00014	98
Longman's beaked whale	*Indopacetus pacificus*				0.00041	126
Melon-headed whale	*Peponocephala electra*	0.0021	88.3		0.00120	117
North Pacific minke whale	*Balaenoptera acutorostrata*					
Pantropical spotted dolphin	*Stenella attenuata*	0.0407	45.1		0.02012	48
Pygmy killer whale	*Feresa attenuata*				0.00449	83
Pygmy sperm whale	*Kogia breviceps*				0.00291	112
Risso's dolphin	*Grampus griseus*				0.00241	65
Rough-toothed dolphin	*Steno bredanensis*	0.0017	62.8		0.00805	45
Sei whale	*Balaenoptera borealis*					
Short-finned pilot whale	*Globicephala macrorhynchus*	0.0237	32.2		0.01498	38
Sperm whale	*Physeter macrocephalus*	0.0010	56.0		0.00059	81
Spinner dolphin	*Stenella longirostris*	0.0443	36.5		0.00699	74
Striped dolphin	*Stenella coeruleoalba*				0.00310	46
Hawaiian Monk Seal	*Monachus schauinslandi*					

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Appendix T-1

Underwater Noise Impacts Review

By Oceanit

Underwater Noise Impacts during Proposed Construction and Operation of the Expanded Honokohau Harbor, Kona, Hawaii

Literature Review and Report For

Jacoby Development, Inc.

By

Oceanit Laboratories, Inc.
R. E. Bourke

November 2006

Underwater Noise Impacts during Proposed Construction and Operation of the Expanded Honokohau Harbor, Kona, Hawaii.

A Review of Recent Research on the Impact of Anthropomorphic Sound in the Marine Environment

Prepared by Oceanit, November 2006

1.0 Introduction

The proposed expansion of the Honokohau Harbor in Kona, on the east side of the Island of Hawaii has raised the concern of potential sound pollution resulting from the construction and operation of this small boat harbor to marine resources.

Noise has become a recognized pollutant in the marine environment (NRC, 2003). Sounds travel farther and faster in water and marine animals have adapted to use these sounds to a greater degree than is generally appreciated by man's air-adapted ears. Far from being the "Silent World" (Cousteau, 1953) the sea is filled with sounds created and used by ocean dwelling mammals, turtles, fish, and invertebrates. Marine noises created by man's activities span a broad spectrum of frequencies and intensities. The impact of these sounds on the marine community likely also spans from "none" to "lethal" depending upon the sound frequency, intensity, and duration. At one extreme the use of high intensity military sonar has been linked to marine mammal strandings, pile-driving has been linked to the death of nearby fish (Hastings & Popper 2005), and the use of open underwater explosives has been linked to whale net entanglement, presumably due to a lost ability to echolocate (D. Ketten, Harvard Univ.). At the lower threshold of aquatic noise pollution anthropogenic sounds may mask important audio ecological clues thereby impacting behaviors such as predator avoidance or the establishment of territories.

Because of increased awareness of the importance of sound in the marine ecosystem and of man's potential to pollute this environment it was deemed prudent to provide a greater degree of review of this subject than is typically offered in the body of an EIS.

2.0 Problem Identification: Noise from Blasting and/or Boat Engines

Excavation to expand the Honokohau harbor will likely involve blasting which will result in short-duration high intensity sounds emanating into the adjacent marine environment. Increased boat traffic from the operational harbor will result in long-term increased sound levels in the harbor area and along transit routes to common fishing grounds.

The ecological role played by anthropomorphic sound in the marine environment has recently received heightened awareness. Evidence from declassified Department of Defense ocean recordings off of San Diego show that background sound levels off-shore of the harbor have increased approximately 10-fold in 30 years. The effects of these sounds in the marine environment have been the focus of increasing research during the past several decades.

3.0 Species Impacted and Probability of Exposure.

Concerns have been raised about the impact of blasting and boat engine sounds on whales, dolphins, turtles, Monk Seals, fish, and coral reef communities. Whales are seasonal visitor to Hawaiian waters from November through March, with the height of the breeding and calving activity during January and February. Honokohau Bay is an occasional resting area of a pod of spinner dolphins during the morning and afternoon periods. A pod of dolphins may be found near the mouth of the harbor where they occasionally bow-ride on boats leaving the harbor. The presence of Monk seals along this coastline is a rarity that would greatly limit the possibility of blast noise exposure to these species. Turtles and fish are known to regularly inhabit waters near, and within, the existing harbor and would definitely be exposed to construction sounds from the harbor.

The sound generated from boat operations would center at the harbor mouth and disperse with the boats along the coastline and out to sea. As such it is likely that all species of concern will be able to hear boat engine sounds at relatively close distances. Whether the level of noise and distance of approach will cause any negative impacts will be species dependent. The sound generated from inland blasting will be greatly muffled by the land buffer (minimum 400-feet) between the new harbor and the coastline. The waters of the harbor will only connect directly to the ocean when the final earth dam is removed that separates the new harbor from the existing channel.

4.0 Experiences from Similar Harbor Construction in Hawaii

Because sufficient amount information necessary to characterize impacts from anthropomorphic sounds not available or undefined, additional insight may be gained from examination of previous similar activities in Hawaii. During construction of the harbor it is likely that explosives will be used to loosen the underlying rock so that physical excavation can take place. Similar techniques have been used recently in the excavation of the Barber's Point Harbor, and the Ko Olina Lagoons on Oahu, as well as the initial construction and expansion of the existing Honokohau Harbor. In none of these cases were underwater sound measurements conducted in nearshore waters. In the cases of the Barber's Point Harbor and Ko Olina Lagoons efforts were made not to conduct explosion during whale season although the distance offshore of common whale migration routes was deemed adequate to mitigate for these sounds. Review of monitoring reports and discussions with monitoring personnel (R. Brock, P. Biengfang, S. Dollar, all of University of Hawaii) did not uncover any evidence of adverse impacts to the marine environment from blasting operations other than direct impacts to substrate in channel areas. The greatest impact at Ko Olina Lagoons and the Barber's Point Harbor appeared to be that Green Sea Turtles were attracted *towards* the construction sites, either by the sounds of construction or the plume of murky water released when the final excavation dam was breached (R. Brock, S. Dollar, personal communication).

The State Division of Aquatic Resources and local fishermen generally acknowledge a decrease in fish abundance relative to proximity of small boat harbors and launching ramps. However, there is ample evidence to correlate this decreased abundance with simple fishing pressure (and in some cases, possibly pollution) without factoring in potential impacts from boat sounds on the environment.

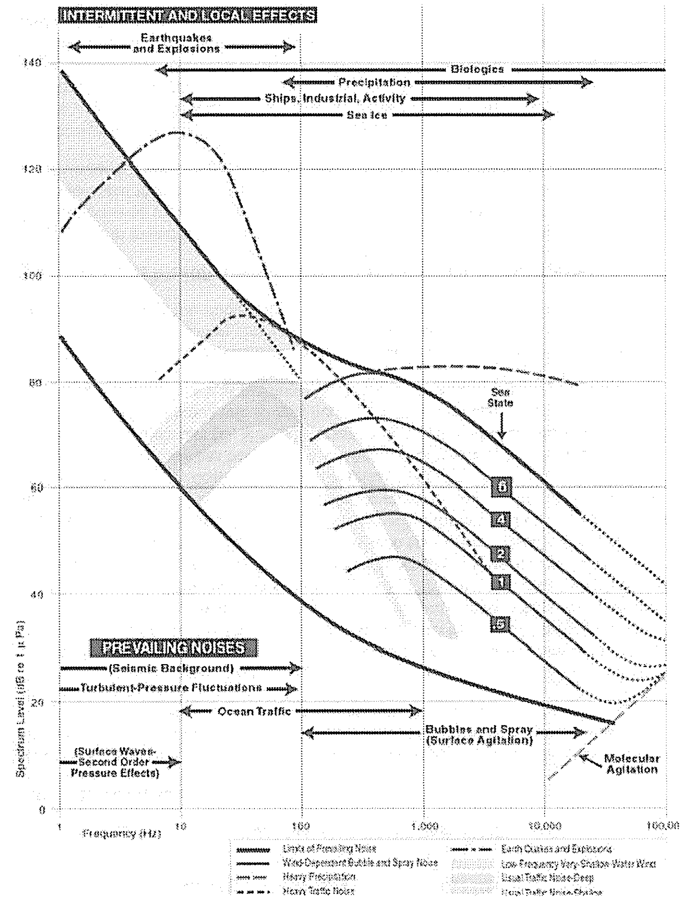

Figure 1. The typical sound levels of ocean background noises at different frequencies, as measured by Wenz (1962). This graph is referred to as the Wenz curves. The sound levels are given in underwater dB over 1 Hz wide frequency bands, which is often written as dB re 1 $\mu Pa^2/Hz$. Reprinted from National Research Council. 2003. Ocean Noise and Marine Mammals. National Academy Press, Washington, D.C. (as adapted from Wenz, 1962) by the National Academy of Sciences.

In two more recent instances sounds generated from pier-pile driving activities at the NOAA Marine Mammal Sanctuary building in Kihei and the expansion of a Coast Guard pier in Ma`alaea, Maui have been monitored. At the Coast Guard facility a sound level limit was set at 160 decibels measured at a distance of 500 feet (NOAA, 2006).

5.0 Natural Background Sound in the Marine Environment

A number of studies have been conducted over the years documenting sounds in the marine environment. Recently the National Academy of Sciences (NRC, 2003) updated a graphic initially devised by Wentz (1962) that displays the frequency and decibel range of common sounds in the marine environment (Figure 1). In this graphic it can be seen that sea state and rainfall can often dominate at frequencies above about 100 Hz. (This is analogous to the sound of rain on an open tin roof). As this graphic is for open ocean conditions, it does not include sounds from waves crashing against reefs or the sounds generated by natural reef biota. General biotic noise over a reef has been measured at 30-50 decibels in the range of 800 to 1600 Hz (McCauley & Cato, 2000), but individual fish and snapping shrimp have been recorded at 14-180 decibels at a distance of one meter. Whale sounds have been measured at up to 162 decibels. Clearly a reef can be a noisy place. If whales can generate sounds up to 162 decibels, then sounds less than 160 decibels would not be likely to cause adverse impact.

6.0 Anthropomorphic Sounds in the Marine Environment

The sounds of concern in this project are those of blasting during the construction phase of the project, and the noise generated by boats and boat engines operating in the harbor and adjacent waters. Explosions generate shockwaves with relatively long period vibrations (low Hz) and high decibels. A one-pound stick of TNT in air will generate a sound of 182 decibels at a distance of 15 feet. The fact that explosives are still used (albeit unwisely) for fishing in many locations around the world is evidence of their potential to cause direct damage. Lethal damage to fish from one stick of dynamite in open water over a reef has been observed to stun fish within a radius of 15-20 feet (Bourke, personal observations in Truk, Marshall Islands). It is not yet known if explosives will be used in the construction of the harbor. If explosives are used, they are likely to be relatively small charges (intended only to fracture the lava for excavation) and will be buffered from the marine environment by at least 400 feet of land. As the shock radius expands, its intensity decreases initially as the inverse square of the range ($1/r^2$: spherical) and then as direct inverse (1/r: cylindrical) further from the sound source. At 400 feet (~120 meters) the intensity would be from 1/120 to 1/15,000 of that at 3 feet (1 meter) and there would be a transmission loss of between 20 to 45 decibels.

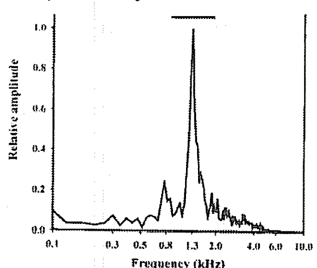

Figure 2. Noise spectrum from a 50-HP outboard. From: Scholik & Hong, 2002

Boat traffic sounds are generated by a combination of the engine type, rpms, propeller design, cavitation of bubbles on the propeller, and hull sounds. Much of the noise attributed to ocean traffic (Figure 1) is from large ocean-going ships. The sounds generated from small boats typical of the Honokohau Harbor will likely be closer to the spectrum measured by Scholik & Hong (2002) of a 50 HP outboard at idle (Figure 2 at right) with peaks between about 0.7 and 4Hz. During high-rpm operations at sea, it is likely that the frequencies generated will spread upwards to 10 to 20 Hz. Scholik & Hong played this recording back to minnows at an amplitude of 142 decibels to approximate conditions in the wild. Others (Green & Moore, 1995) report intensities as high as 175 dB.

7.0 Assessment of Sound Impacts

To make an absolute determination of potential environmental impacts from sound it would be necessary to understand the

- intensity, frequency, and duration of the sound generated,
- susceptibility of the species being impacted,
- threshold of intensity and duration at which impacts occur,
- probability that the species will be exposed to greater than threshold limits, and
- type of impact expected for each specie at each significant life stage
  - Life Function Threat (air bladder, ear, or other tissue damage)
  - Behavioral Change (startling, evasion, area avoidance, predator avoidance, masking)
  - Population Effects. (larval impacts, territory size impacts, stress impacts)

8.0 Species Susceptibility

Cetaceans, whales and dolphins have been shown to have the capacity to both hear and generate a broad range of underwater sounds. Indeed, their use of sound for echo-location and communication make these creatures susceptible to sound pollution. But even very intense underwater noise, if for short duration, may not elicit adverse responses from marine mammals. This was aptly stated by C. Clark and A. Frankel (May 14, 1997) who investigated marine mammal responses to very loud sounds in Hawaii and concluded that "Presently there are no MMRP results indicating that any species shows any biologically significant adverse response to ATOC or ATOC-like sounds...". Adverse impacts of lower intensity noise, such as from small boat engines, have been even more difficult to quantify. While some researchers (T. Norris, "The Effects of Boat Noise on the Acoustic Behavior of Humpback Whales, 1994) have shown that whales changed the rhythm and tempo of their "songs" when subjected to boat traffic noise, the assertion that these changes lead to behavioral changes or are at all deleterious are uncertain. The National Academy of Sciences (NRC, 2003) concludes that "Unfortunately, existing data are insufficient to predict accurately any but the grossest acoustic impacts on marine mammals. Little information exists to describe how marine mammals respond physically and behaviorally to intense sounds and to long-term increases in ambient noise levels."

Green sea turtles are on the EPA protected species list due to their resemblance to Hawksbill turtles which are on the endangered species list. While Hawksbill turtle numbers appear stable (or at most slightly increasing) in Hawaii, there is abundant data showing a dramatic increase in green sea turtle populations during the past 3 decades (Balazs, Personal communication). Green turtles are sensitive to sounds in the 300 to 400 Hz range (NRC 2003) with acuity dropping off rapidly above and below these levels. This would seem to explain the common phenomena where a boat will approach a turtle basking on the surface, but the turtle will only startle and evade after it lifts its head free of the water and sees the approaching boat. The proposed harbor area is not critical habitat for either the hawksbill or green sea turtles.

Fish possess at least three means of sensing sound; an inner ear, a lateral line, and a gas bladder. Each organ adds sensitive to a different range of sound frequency. Sound pollution may mask natural sounds causing a variety of ecological changes. For instance, some fish emit sounds to protect a home territory or to find mates of the same species. Loud anthropogenic background sounds will mask the fish sounds thereby reducing the area of territory they can claim on a reef and decreasing the distance at which they can call to a potential mate (Mann & Lobel, 1997). Loud background sounds could also mask the sound of approaching predators. Although it appears highly doubtful that noise levels from harbor excavations or boat traffic will have sufficient intensity to cause physical damage, there are a broad number of unanswered questions regarding potential secondary impacts. The sound of underwater pile-driving is much more intense than the sound of small boat engines or even compared to explosions 400-plus feet inland. The lethal impact of this repetitive sound on fish was investigated recently during the re-construction of the Oakland Bay Bridge in California. Speaking specifically about the impacts of pile-driving sound on fish Hastings and Popper (2005) conclude that "---the body of scientific and commercial data currently available is inadequate for the purpose of developing more than the most preliminary scientific supportable criteria that will protect fish from pile driving sound."

9.0 Conclusion and Mitigation Recommendations

Our ability to accurately measure the levels of sounds in the marine environment far exceeds our ability to detect any ecological impacts of these sounds on the marine community. The inability of governments to make policy on this issue is linked to the paucity of decisive information.

To mitigate impacts related to noise generated by construction activities, such as blasting and pile driving, a program to monitor sound levels and the presence of marine mammals and sea turtles should be implemented. Construction activities will be adjusted if whales, monk seals, dolphins or sea turtles are in the vicinity. Periods of possible presence include the height of the whale breeding season is in the months of January and February. Also, porpoise typically vacate nearshore waters in the afternoon.

If it is not possible to avoid blasting during periods when marine mammals may be in the vicinity, then it would be appropriate to place a look-out at a vantage point near the harbor to insure that no marine mammals (including monk seals) are within a quarter mile when blasting occurs. In this instance procedures should also be followed similar to those established at Ma`alaea Harbor by the Coast Guard to limit underwater sound intensity to less than 160 decibels at a distance of 500 feet off shore.

Further, keeping the land bridge closed to the ocean until all major pile driving and blasting are completed will further avoid adverse impacts.

Knowing that sea turtles appear to be attracted to new harbor sites, particularly during construction, it would be prudent to stage a watch for these animals so that harm can be avoided by allowing these animals to voluntarily remove themselves from the potential area of impact.

There is no evidence that the level of sound generated by boat motors or harbor construction will have any significant adverse impact on fish or invertebrate populations in the adjacent waters. Simple fishing pressure (and in some cases, possibly pollution) are known to effect far greater impacts without factoring in potential impacts from boat sounds on the environment.

Construction and operation of the expanded Honokohau Harbor should offer scientists an excellent opportunity to test hypotheses on thec impact of construction and operation noise of a harbor on the adjacent marine community. It is recommended that the developer actively cooperates with researchers at the adjacent Kaloko Honokohau National Park where similar research activities are already underway.

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Appendix T-2

Ambient Noise Measurements
and Estimation Study

By Marine Acoustics, Inc.

Honokohau Bay Ambient Noise Measurements and Estimations for the Kona Kai Ola Project

Prepared For:
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MAI-642-U-07-051
24 June 2007

MARINE ACOUSTICS, INC.
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Research – Operations – Engineering – Design - Analysis

Marine Acoustics Inc. Technical Report

Honokohau Bay Ambient Noise Measurements and Estimations for the Kona Kai Ola Project

Prepared By:

Dr. Adam Frankel
Stanley J. Labak

24 June 2007

Introduction

This report is an attempt to predict the changes in the ambient noise level that would results from the completion of the Kona Kai Ola project. This project would result in an increase from the existing 272 slip harbor at Honokohau to a combined 1,072 slips. Existing ambient noise data have already been collected from a recorder in Honokohau Bay for the Kaloko-Honokohau (KAHO) National Historical Park (Frankel and Driscoll-Lind, in prep). These empirical data were used in conjunction with acoustic propagation models in order to predict the effect of the increase in vessel traffic on the acoustic environment of Honokohau Bay.

The primary issue of concern with a potential increase in boat traffic is its potential impact on the marine mammal and sea turtle species that inhabit or visit the Honokohau Bay area. The following is a brief description of the utilization of the bay by several species and discussion of the issues of concern. The southern area of the park, near the Honokohau Harbor entrance, is a documented resting area for schools of Hawaiian spinner dolphins (*Stenella longirostris*). Humpback whales (*Megaptera novaeangliae*) and Hawaiian monk seals (*Monachus schauinslandi*) are also visitors to the Bay. Vessel noise has the potential to mask marine mammal sounds (communication) and may cause temporary changes in hearing sensitivity (Erbe 2002). It can also displace marine mammals from their habitat. Gray whales (*Eschrichtius robustus*) temporarily abandoned a calving lagoon in Baja California during an increase in vessel traffic (Gard 1974; Bryant 1984). There is some evidence that humpback whale (*Megaptera novaeangliae*) mothers and calves moved offshore of Maui in response to recreational vessel activities (Salden 1988; Glockner-Ferrari and Ferrari 1990) although this may have been a short-term response. Honokohau Bay provides habitat for many species of fish, and while there has been much less research focusing on the effects of anthropogenic noise on fish, some response have been documented. Studies have reported that high sound levels can damage the inner ear sensory cells, produce hearing loss (threshold shifts), elicit stress response and alter the behavior of fishes (Popper et al. 2004). Lower

noise levels can also lead to temporary reduction in hearing sensitivity in fish (Scholik and Yan 2002; Amoser and Ladich 2003). Honokohau Bay is also a primary feeding area for resident green sea turtles (*Chelonia mydas*), with 70% recapture rate of 186 tagged from this area (NOAA Fisheries Marine Turtle Research Program). Hawksbill sea turtles (*Eretmochelys imbricata*), although much less common, are also regularly sighted within the park. Subadult green turtles hearing was measured between 100 and 600 Hz, with their best sensitivity occurring at 300 Hz With a threshold of ~92 dB (Bartol and Ketten 2006). This is approximately equal to the hearing of dolphins at that frequency. However, dolphins are high-frequency specialist and are about 40 to 50 dB more sensitive at their best frequency than turtles.

In order to attempt to quantify the potential impact of the proposed traffic increase due to the Kona Kai Ola project, this report will: a) describe the equipment and analyses used to quantify the existing noise structure in the Honokohau Bay area, b) describe the current ambient noise conditions, c) estimate the traffic change (based of the current traffic study and the proposed increase in the number of vessels present), d) quantify the potential future ambient noise condition, and finally e) estimate its potential impact of the environment.

Methodology

Data Collection

1. Cornell University 'pop-up' recorders

The system used to gather the *in situ* ambient noise data for the KAHO study was developed at Cornell University and is called a 'pop-up' buoy. As the name implies, this system is deployed in the ocean, where it collects data, until it is commanded acoustically to release from its anchor and 'pop-up" to the surface, where it is recovered and analyzed. A 'pop-up' is an autonomous acoustic data logger enclosed within a seventeen-inch diameter glass sphere housing. The hydrophone used by the 'pop-up' buoy is an externally mounted High-Tech Inc HTI-SSQ 94. The hydrophone for each 'pop-up' buoy is calibrated separately and its sensitivity curve and calibration results are stored for latter use. Acoustic signals are low-pass filtered at 16 kHz and then digitized at a 33.3 kHz sampling rate. Recorded data are stored internally on 80 GB hard drives. The signal processing and storage hardware are all custom-built components of the pop-up recorder. A total end-to-end calibration of each 'pop-up' buoy is generally not conducted, but a series of tests are performed on each buoy and compared to that of a know and completely calibrated buoy. The measured differences between any 'pop-up' and the calibrated 'pop-up' are then used to effectively calibrate the *in-situ* recordings. This calibration procedure was used on the data reported on in this report.

Acoustic data were collected for nine months from Sept 17 2004 to May 29 2005 with a series of three Cornell University 'pop-up' recorders. The pop-ups were deployed, near the bottom (to prevent storm damage), in approximately 450 meters of water at 19° 41.02'N, 156° 3.19' W (see Figure 1). This location is approximately 1 km offshore of the park boundary, but the location was chosen to ensure that large winter waves would not disturb the pop-up recorder. Each pop-up was deployed for approximately three months. The first recorder sampled five contiguous minutes out of each half-hour. The subsequent two recorders sampled four contiguous minutes out of each half-hour. The change in sampling procedure was necessary to ensure that the planned four recorders would capture data from an entire calendar year. Unfortunately, the fourth recorder failed due to salt-water intrusion into the hydrophone cable, so this data is not available.

2. Traffic Study

A study of the marina boat traffic was conducted by the firm, Moffatt and Nichol and is included as Appendix P of the Kona Kai Ola EIS. That report is the basis of the data presented in this section.

The Moffatt and Nichol's study, conducted observations of boat traffic on five separate days in an attempt to categorize the existing traffic patterns of the existing Honokohau small boat harbor. The five days selected included: a) the Saturday and Sunday of a holiday weekend, b) a Saturday when a fishing tournament was scheduled, and c) a Saturday and Thursday (i.e., "typical") when no special events were scheduled. Table 1 identifies some of the statistics reported, that are pertinent to an acoustic analysis.

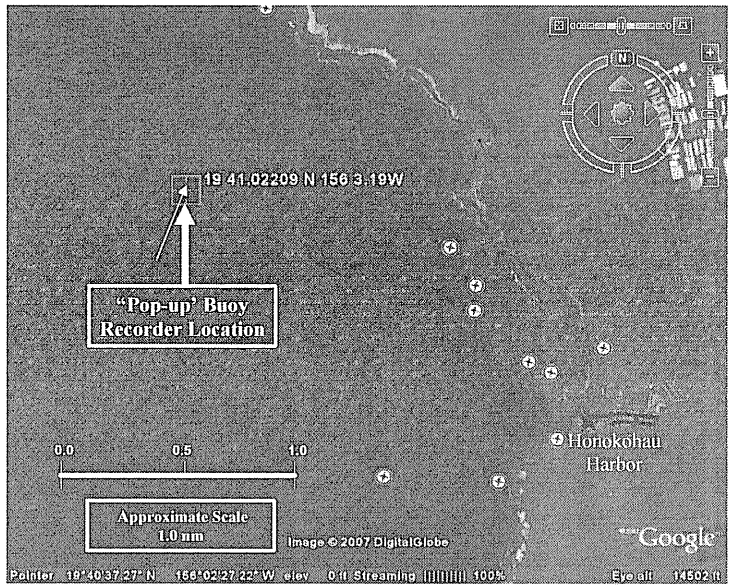


Figure 1: Location of Recording Buoy (Square Box) relative to Honokohau Harbor

The significance of this data from an acoustic point of view is that for any selected day, the average total number of boats either entering or leaving the port per hour is roughly the same, approximately 25 boats per hour (BPH). A review of the data tables in the Moffatt and Nichol's Study indicates that approximately 50% of the boats sighted are sailboats, while the remainder are power boats. That study also predicts that that ratio will remain approximately the same for the proposed 800 slip harbor. For the purpose of this analysis, the sailboats, regardless of whether they are under power or not, are generally much quieter than the powerboats, especially when the powerboats are at their higher speeds (e.g., sailboats have underwater acoustic source levels are greater than 20 dB less than those of power boats). Therefore, the contribution that sailboats make to the ambient noise levels are negligible and not considered further in this analysis.

Table 1 Pertinent Statistics from the Moffatt and Nichol Study

Category	Weekday	Range of Total Hourly Boat in Channel Counts*	Hours Observed	Average Total Boats per Hour* Averaged Over the Hours Observed
Holiday	Saturday	15-38	7 AM – 5 PM	26.8
Holiday	Sunday	15-37	7 AM – 4 PM	25.9
Fishing Tournement	Saturday	11-110	6 AM – 5 PM	22.2
"Typical" Day	Thursday	11-56	6 AM – 5 PM	27.5
"Typical" Day	Saturday	17-95	6 AM – 5 PM	23.3

Note: * Includes both inbound and outbound vessels.

Operations at the Honokohau Harbor indicate that powerboats typically move slowly to reduce wake in the harbor and channel until the final channel buoy is passed on an outbound passage. After which, they rapidly increase speed and travel out to deep water. And the reverse is true for inbound boats. For the purposes of this analysis, the location of that buoy is estimated to be on the north side of the channel, at the 20 fathom curve, and it is designated as the final channel buoy. Since the vast majority of the boat noise is made during the high speed portion of their transits, this location is the basis of the acoustic modeling that follows later in this report. Also, it should be noted that inside of the 20 fathom curve, underwater sound produced by the boats typically interacts often with the bottom and the ocean surface. Therefore, the lower levels of sound produced in the shallow water attenuate in the water faster than outside the 20 fathom curve and is further reduced as a contributor to the overall noise level in the bay. This does not preclude these boats from raising the noise level in their immediate vicinity, but acoustic

transmission loss (TL) and a lower source level (SL) ensure that this noise is localized near each individual boat.

The 3,000 ft (914 m) isobath is located approximately 1.5 nautical miles (nm) (2.8 km) offshore. For powerboats traveling at 10 knots or more this transit should take less than 9 minutes. Beyond this range their contribution to the near-shore ambient noise rapidly decreases with range due to acoustic TL, and is not considerate further. Therefore, of the approximately 12.5 powerboats per hour (i.e., 50% of the 25 total BPH transiting the channel), there are about two boats within two nautical miles of the recording buoy at any given time during the day. The exact course each boat takes from the final channel buoy to deep water varies, but it is assumed that, on average most head generally out to sea for a mile or two before drastically changing course. In order to simplify this analysis, a single course is assumed for all power boat travel. This course proceeds directly due west from the final channel buoy to the deep water. As a rough approximation, the contribution to ambient noise hear at the recording buoy due to boats moving north of this "average" course effectively compensates for (i.e., averages the noise received from) those boats traveling south of this course. Therefore, for simplicity, all boats are assumed to travel east or west near this track.

Analysis Procedure

1. Received Signal Processing

The raw recorded data from the Cornell 'pop-up' were transformed into time-stamped AIFF files by the staff of the Cornell Laboratory of Ornithology Bioacoustics Research Program. These raw data files were processed with a suite of custom-analysis programs written in Matlab (Mathworks 2000). The first program used a standard Matlab spectral analysis code to generate a spectrum for each five (or four) minute sample and stored the resulting pressure vector in a summary matrix for the entire month. Spectrum parameters were 4096 point fast Fourier transform (FFT), with a Hamming window and 50% overlap.

Each matrix was then sorted within each frequency bin, producing an ascending sound pressure level within each frequency bin. Summary statistics were then generated for each frequency bin, specifically the 5th, 25th, 50th, 75th and 95th percentile sound pressure level for each frequency (e.g., for the 95th percentile values, 95% of all of the received values at this frequency, were at this level or below it). These values were plotted for each month, and an example is shown in Figure 2.

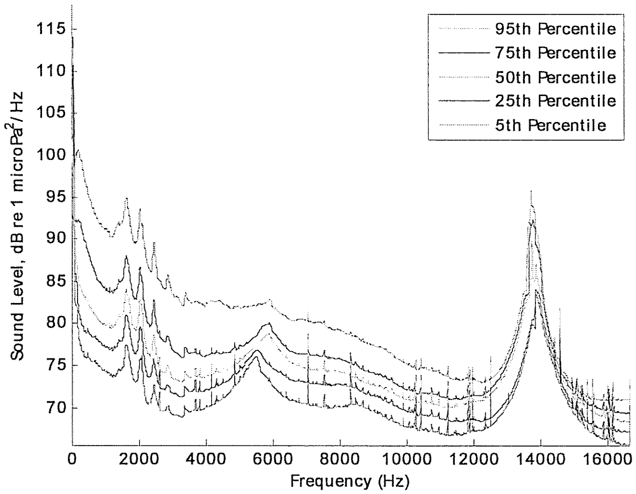


Figure 2: A sample summary presentation of spectral information for a month. The large spike in sound pressure near 14 kHz is due to self-noise of the recorder and does not reflect the levels in the environment. Data up to ~ 12 kHz is considered reliable and representative.

The received level of selected frequencies for each sample was exported to a text file, along with date and time information. These data were used for statistical tests of the

trends in ambient noise level. The entire nine-month dataset was used to test differences in day v. night and weekend v. weekday periods.

2. Acoustic Modeling

The model used to estimate in-water acoustic propagation was the Navy Standard Comprehensive Acoustic System Simulation (CASS) / Gaussian Ray Bundle (GRAB) model (Keenan, 2000). This model is a range dependent program that computes the TL associated with the potential propagation paths between a source and a receiver. This Gaussian Beam model have been demonstrated to successfully model the complex underwater sound propagation for frequencies as low as 50 Hz and as high as 600 kHz.

TL is the loss in intensity of sound as it travels from the position of the acoustic energy source to the position of a virtual receiver. Underwater acoustic propagation is greatly affected by the sound speed structure of the water which in turn is controlled by temperature, salinity and depth in the water column. For this modeling, a typical February sound velocity profile (SVP) of the water column for 19.3° N, 157.0° W from the Generalized Digital Environmental Model (GDEM) database (GDEM, 2007) was used. Analysis of this profile against profiles from the other three seasons for this location showed that the TL was similar. Thus this one profile was used to approximate year-round TL in the Honokohau Bay area.

The results of the CASS/GRAB model runs for this site are shown in Figures 3 and 4. Figure 3 shows the acoustic rays propagating from a source, which is located at the final channel buoy for the harbor entrance, towards the location of the 'pop-up' buoy. The buoy is approximately 1.6 nm (3.0 km) from the source at a depth of 1,480 ft (450 m).

Figure 4 shows the TL for three depths, 1,300, 1480, and 1,600 ft (396, 450, 488 m). Note that as one goes deeper, it is necessary for the curve to start at a farther range from the source. This is due to the fact that for this model run, only in-water TL is displayed. For the range of interest (i.e., from the source to the 'pop-up' buoy – 1.6 nm) a red arrow identifies the correct TL, approximately 68 dB.

It must be emphasized that this modeling analysis is for 300 Hz only, even though the frequency range produced by a small, fast boat covers frequencies from 100 Hz to 20 kHz. It was chosen because the resultant TL would be reasonably accurate for frequencies between 100-600 Hz, where much of the ambient noise energy occurs. This is because typically by 1.4 kHz or so, the boat's SL has decreased by 20-30 db, with this trend continuing until SL is reduced by 40-50 dB at 20 kHz.

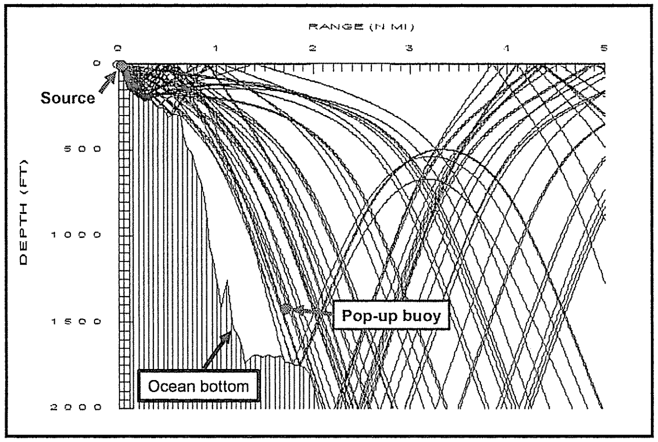


Figure 3: Acoustic Ray Plot from Final Channel Buoy to 'Pop-up' Buoy

A similar model run was conducted for the case where a boat has transited due west from the final channel buoy and is due south of the 'pop-up' buoy. The resulting TL for a range of 0.8 nm (1.5 km) was 55 dB. Therefore, the estimated average boat SL was between 55 – 68 dB above those values recorded by the 'pop-up' buoy.

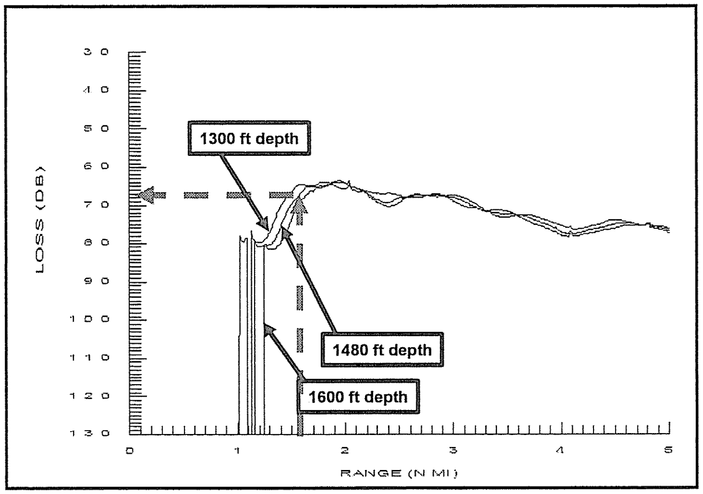


Figure 4: Transmission Loss Plot from Final Channel Buoy to 'Pop-up' Buoy

Results

Monthly Trends

The data in Figure 5 is a plot of all measured 100 Hz sound level over the nine moths of the recordings. It also shows a clear increase in that measured ambient noise at the beginning and the end of the year. This is as expected and it is concurrent with winter storms and high waves. It is also the time when humpback whales migrate into the area. Humpback whale song has significant energy in the 100 Hz band (Fristrup et al. 2003). Both of these factors could drive the increase in low-frequency sound in the winter months. Thus the data set appears to be reasonable sensitive to expected seasonal ambient noise changes due to naturally occurring phenomenon.

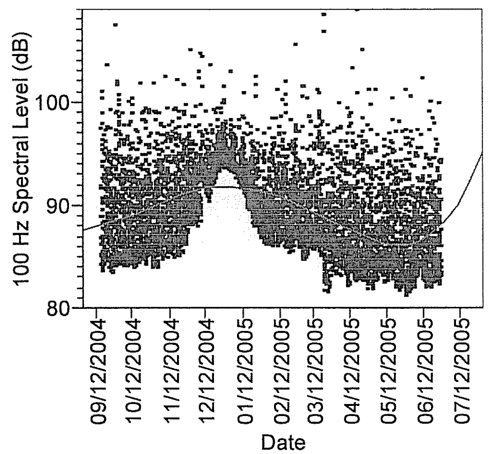


Figure 5: 100 Hz Sound Level Over the Nine Month Observational Period. Showing increased sound levels attributed to higher winter waves.

Weekday v. Weekend Trends

Examination of the monthly spectrograms showed no evidence of a weekend v. weekday pattern (see Figure 6). The selected analysis frequencies were compared with a t-test. No difference was seen in any of the analysis frequencies.

Diurnal Trends (Day v. Night)

Examination of the data showed a clear diurnal pattern (see Figure 7 and 8). This was confirmed with t-tests for each of the analysis frequencies (see Table 2). Each frequency was statistically significantly different, with daytime levels being higher at all frequencies. The noise pattern shown in Figure 8 is consistent with known vessel operational patterns.

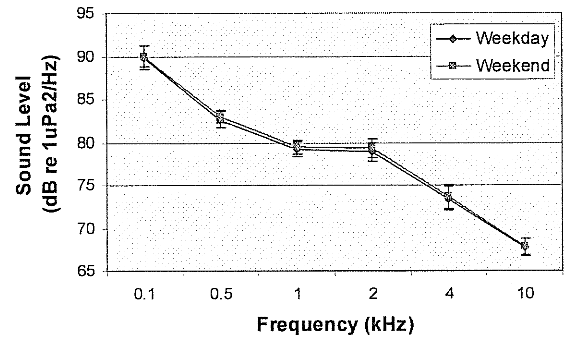


Figure 6: Comparison of median Weekend and Weekday Sound received levels. No significant difference was seen between weekend and weekday sound levels.

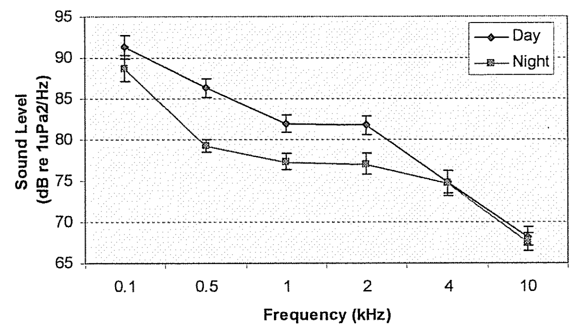
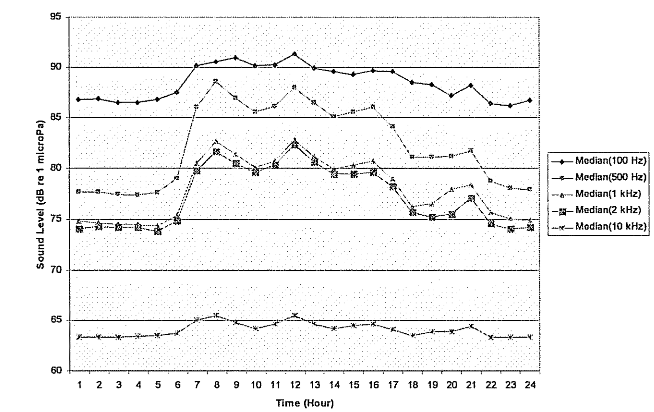


Figure 7: Median daytime Noise levels were statistically significantly greater during the day than at night (statistical details in Table 2).

Table 2: Details of T-Tests for Each Frequency. Statistically significant differences were found at all frequencies, with daytime values being higher than nighttime values.

Frequency	t score	Degrees of Freedom (DF)	probability
100 Hz	-10.491	570	≤.0001
500 Hz	-42.524	570	≤.0001
1 kHz	-27.73	570	≤.0001
2 kHz	-22.615	570	≤.0001
4 kHz	-8.473	570	≤.0001
10 kHz	-3.487	570	0.0005



Data from Frankel and Driscoll-Lind (in prep), Courtesy of Kaloko-Honokohau NHP

Figure 8: Hourly Sound Levels.

The day/night comparison is the only one where statistically significant differences were noted. The potential cause of the day/night difference was then examined. The differences in day/night wind patterns were examined, because wind can contribute to ambient noise directly or through wave mechanisms. The mean windspeed during the day was 8.1 knots while during the night it was 5.8 knots. However, the Wenz Curves predict that this increase in day wind speed over night windspeed would only

increase ambient noise over the 100 Hz – 20 kHz frequency range (Wenz 1962) (i.e, over the entire measured frequency range) 1-2 dB, much less than that observed in Figure 7. Also, the observed data show increases only up to 2 kHz, with no differences above 4 kHz between night and day. Since Honokohau harbor is primarily a tourist/recreational harbor, this difference in ambient noise levels is taken to be primarily the contribution of vessel activity, i.e. the nighttime values are taken as approximately natural ambient and the daytime values reflect the contribution from vessel activity.

It should be noted that the average "night" noise levels as identified in Figure 7, are still about 10-15 dB higher than the expected average ambient noise level for "light" to "moderate" wind and wave conditions for frequencies from 10 Hz to 4 kHz, per the Wenz generalized ambient noise spectra (Richardson, 1995). This increased level in the general ambient noise level for the area over those predicted in the Wenz curves is probably primarily due to the fact that those curves are for deep, open-ocean and this is a coastal area. The expected contributions to ambient noise from breaking and crashing waves, along with biological sources (e.g., snapping shrimp, parrot fish breaking coral, etc.) account for this 10-15 dB difference. The reported nighttime ambient noise levels are generally consistent with those reported for Kaneohe Bay (Au, 1990), in which a 70 dB re 1 $\mu Pa^2/Hz$ ambient noise level at 20 kHz was typical.

Estimated Boat Source Levels

Estimates of the boat source levels (SL) can be obtained by using the TL values determined previously (i.e., 55-68 dB) to correcting the average "day" received sound levels in Figure 7 by the equation:

$$RL = SL - TL$$

Where: RL = Received Level
SL = Source Level
TL = Transmission Loss

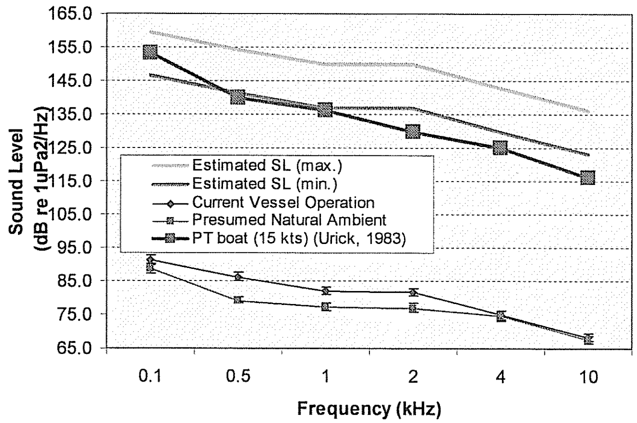


Figure 9: Estimated Source Levels of Boats in Honokohau Channel.

Figure 9 shows the results of this adjustment for TL. The range of estimated SL, over the frequency spectrum varies from the minimum SL shown in green, to the estimated maximum SL, shown in light blue. For comparison, the SL spectrum for a Navy patrol boat (PT boat) traveling at 15 knots is shown in purple (Urick, 1983). Additionally, these source levels are consistent with those reported for civilian small powerboats in Richardson (1995).

Now that the range of SLs has been estimated, they can be applied to the modeled boat distributions for the new harbor, to estimate the change in ambient noise at the 'pop-up' buoy after the harbor expansion is complete. The original geometry used to model TL assumed that the majority of boats travel due west from the last channel buoy towards the open ocean. This geometry assumed that there were typically two powerboats present on this track at any given time of the day (i.e., during daylight hours) contributing to the

ambient noise received at the 'pop-up' buoy. And, this assumption was validated by the small boat traffic study.

If the new harbor is completed, this number of powerboats is expected to approximately quadruple. Currently there are 272 slips in Honokohau Harbor, of which 120 are commercial slips. The proposed project would add 800 slips to a produce a total of 1072 slips. Therefore, eight powerboats would then contribute to the increased ambient noise received at the 'pop-up' buoy for the enlarged harbor. Assuming the geometry remains roughly the same (i.e., the boats take the same track to deep water) each boat's noise will experience a different TL while propagating noise to the 'pop-up' buoy because of their different ranges from that buoy. The range of TLs experienced by the boat-generated-noise has previously been identified as 55-68 dB. Assuming all of the boats have the same nominal SL, an increase of 9.7 dB maximum (i.e., at the 200-600 Hz region) in ambient noise, would be expected to accompany the new harbor, with an average of 8 boats on the channel track at any given day-light period.

If the additional slips had a rate of activity that was one-half of the current slips, then we would predict an effective doubling of vessels activity, or four boats contributing to the ambient noise at any given time during daylight hours. This would result in a maximum ambient noise increase of about 2.9 dB at the 'pop-up' buoy for the lower frequencies. These predictions are presented in Figure 10.

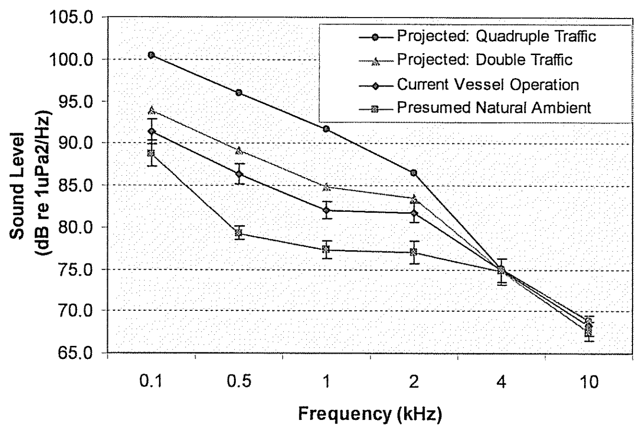


Figure 10; Predicted ambient noise levels at "Pop-up' Buoy Site.

The predicted ambient noise levels at the 'pop-up' buoy only present a portion of the potential increases to ambient noise in the Honokohau Bay, that of those portions of the bay roughly a half mile or more from the assumed powerboat channel modeled. The area that is not represented by Figure 10 is the area within about 0.0–1.0 nm (0.0–1.8 km) of the modeled boat channel. Here the sound field around each individual boat (i.e., the closest boat) dominates, while the other boats' noise field contributes slightly. Assuming a nominal 155 dB boat source (at about 100 Hz) and following the PT boat spectrum in Figure 9, the typical boat has a single frequency (1 Hz band) noise field of 135 dB at 10.9 yards (10.0 m), 115 dB at 109.0 yards (100.0 m), and 100 dB at 615.3 yards (562.3 m) from the boat. And the broad band levels (i.e., summing the acoustic energy across the 100 Hz – 12kHz spectrum) would yield a field of approximately 156 dB at 10.9 yards (10.0 m), 136 dB at 109.0 yards (100.0 m), and 121 dB at 615.3 yards (562.3 m) from the boat. Essentially, small areas of boat-generated noise are constantly moving and ensonifying the area around the modeled boat channel. By quadrupling the number of boats using the modeled track at any time, the number of more intensely ensonified areas has also been quadrupled. On average, the ambient noise level (per Hz) along this track

would nominally be about 115-120 dB during the day, with louder levels as boats pass by.

Conclusions

Historically, the thresholds for Level A and B takes, under the Marine Mammal Protection Act (MMPA), for broadband signals has been 180 and 160 dB re 1 μPa, respectively. In recent years, these levels have been amended to include energy versions of these thresholds, 180 and 160 dB re 1 μPa^2-s. For the typical small boats analyzed in this report, underwater sound could only possible cause Level B takes (due to the maximum broad-band sound level produced), and this only when an animal is within 10.9 ft (3.0 m) of the boat. The only reasonably foreseeable source of Level A takes would be collisions of marine mammals with a boat or an object suspended/deployed from a boat, and this possibility seems negligible. Therefore, although Level B takes could occur, and would be approximately four times more likely to occur if the new harbor is built, it seems unlikely that the very maneuverable dolphins would not easily avoid transiting boats. Whales, although less agile than dolphin, would typically be more rare in the vicinity of the transiting boats, therefore the likelihood of Level B whale takes also seems very low.

Although received levels between 120 – 160 dB re 1 μPa, or re 1 μPa^2-s, do not technically cross the threshold of a take, received levels in this range have been observed to cause changes in marine mammal behavior (Richardson, 1995). This consideration is especially important for the species discussed in the Introduction of this report. Recent long-term studies have shown that an increase in the number of dolphin-watching vessels resulted in reduced abundance of bottlenose dolphins in Australia (Bejder et al. 2006b). This decline in abundance has been interpreted as the abandonment of the area by those individuals that respond more to the presence of dolphin-watching vessels (Bejder et al. 2006a).

Spinner dolphins have remained in Honokohau Bay following the creation and expansion of the current harbor. However, the size of spinner dolphin schools has decreased since the 1989-1992 period (Ostman-Lind 2004) and increases in the numbers of medium to high level aerial behaviors have been observed following approach by motorized vessel (L-V and Duran 2006). These data indicate, but do not conclusively prove, that the existing level of human activity is affecting the behavior of spinner dolphins. -Therefore, increases in ambient noise, numbers of vessels and numbers of dolphin-vessel interactions that will result from the completion of the Kona Kai Ola project has the potential to produce cumulative or long-term effects that may not be adequately represented by acoustic measurements alone.

The increase in ambient noise level predicted by the increase in vessels traffic could be offset through a variety of mechanisms. Factors contributing to the generation of underwater noise by small boats include: hull size, design and cleanliness, motor type, age, mounting, and general maintenance, propeller design, size and condition and vessel speed. Improvement in any of these factors for a specific boat could reduce its projected noise and its contribution to the overall sound field. As an example, if boat speed was restricted to less than 10 knots, vice an estimated 15-20 knot transit speed beyond the final channel buoy, a reduction in each boat's SL of over 10 dB could be realized.

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Appendix T-3

Acoustic Analysis of Potential Impacts

By Marine Acoustics, Inc.

Acoustic Analysis of Potential Impacts from the Kona Kai Ola Construction Project

Prepared For:
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MAI-642-U-07-054
24 June 2007

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Research – Operations – Engineering – Design - Analysis

Acoustic Analysis of Potential Impacts from the Kona Kai Ola Construction Project

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Report No. MAI-642-U-07- 054

Executive Summary

This report consists of a noise analysis of the construction of the Kona Kai Ola project on the Island of Hawaii. The objectives were: to predict Received Levels (RLs) during the construction, and to analyze the impact on in-water marine mammals from these same operations. Five spatial positions were selected to document the predicted noise levels in and near the ocean. They included three terrestrial positions on/near the beach and two in-water locations. The scenario assumed for this analysis includes: a) the explosive removal of bedrock, b) the dredging of the loose rock after blasting, and c) drilling of holes for piling installation.

As a reference point to the received levels predicted in this report, the Marine Mammal Protection Act (MMPA) (i.e., one of the primary United States' law applicable to protecting marine mammals) as modified slightly by the National Defense Authorization Act (NDAA) of 2004, was identified as establishing the definitions of Level A and Level B harassment. For the purposes of this document, the specific criteria and calculation techniques utilized in the "Final Environmental Impact Statement (FEIS) for Shock Testing *Seawolf* Submarine" and "Final Environmental Impact Statement Shock Testing *U.S.S. Churchill"* (DoN 1998 and 2001) to estimate Level A and Level B harassment were replicated here and used for explosive analysis. Broadband levels used in pile driving and seismic survey were extrapolated to non-impulsive threshold. And in-air broadband missile criteria were used for airborne noise thresholds.

The calculations and model conducted included: 1) source level (SL) estimation based on standard explosive similitude equations and Net Explosive Weight (NEW) for the explosive rock blasting, 2) acoustic propagation models (specifically, the Navy Standard Comprehensive Acoustic System Simulation (CASS) / Gaussian Ray Bundle (GRAB) model) for in-air and in-water transmission loss (TL) estimation, and 3) utilization of the best available data from the Navy standard underwater acoustic databases and atmospheric data from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA). The results from the atmospheric, underwater, and seismic propagation model include acoustic ray and TL plots for each source/receiver site combination. The specific TL for each receiver site was then identified and convolved with the SLs for each of the sources. The resulting received levels at each site for each source were then documented.

In conducting this analysis, the best available scientific, environmental, geologic, and meteorological data were obtained and used to calculate the TLs and subsequently to predict the RLs at the five receiver sites. Additionally, throughout this analysis, conservative assumptions were made. Therefore, the results presented here do not represent the full range of TL, which could occur, but an estimate of the typical nominal minimum TL (and therefore nominal maximum RLs) that can be expected for most days throughout the year. The results are not a "worst case" result, because there could be cases with stronger near-ground cooling or wind conditions which could increase the RLs, but days with these conditions would be infrequent and only represent an estimated 10-15 dB higher RL. Similarly, environmental conditions could greatly increase the TL and reduce RLs, and effectively make the noise from the modeled sources indistinguishable from ambient noise.

The estimated nominal, but conservative RLs for the individual non-explosive construction method sources show that the criteria for Level A harassment of marine mammals were never exceeded by these RLs for neither in-water nor in-air conditions. However, these thresholds could be exceeded by the explosive blasting used to create the new harbor. For both the in-air or in-water acoustic propagation, this only occurred when an animal was within about 200 meters (656 ft) of the explosion. This condition could only occur when the explosive source was at locations farthest north in the new harbor and closest to the existing harbor. This condition mandates that a safety range out to at least 200 meters (656 ft) radius from the source be shown to be clear of all marine mammals and sea turtles prior to each blast to preclude potential Level A takes.

Further, the data indicated that the in-air RLs for the explosive sources would exceed the assumed 100 dBA re 20 μPa threshold for Level B harassment of pinnipeds for ranges out to about 731 meters (2,400 ft) This threshold is nominally for pinnipeds, but it should be extended to marine mammals and sea turtles too. Therefore, an in-air safety buffer of at least 731 m from any explosive source is proposed, that should be maintained and found clear of marine mammals (hauled out or on the oceans surface) and sea turtles (basking or beach) prior to any blasts. It should be noted that although a receiver site was not modeled specifically in the existing harbor, that area is often within the range of this safety buffer and that extra care should be taken to ensure that no marine mammals or sea turtles are in the existing harbor prior to any blast where Level A sound pressures are predicted to occur.. Analysis of the most restrictive Level B in-water, explosive threshold shows that it is only exceeded when a animal is closer than 300 m (984 ft) from the explosive source. Thus, an in-water safety buffer of 300 m is established to reduce the possibility of Level B takes to a negligible level.

Although the possibility exist for Level B impacts to marine mammals, analysis of the marine mammal distribution and movement as predicted by the AIM model, indicates that this is very unlikely situation. Therefore, it is expected that there will be much less than 0.5 Level B takes, with or without mitigation. But the mitigation safety buffer must still be enforced to preclude the unlikely possibility of marine mammals or sea turtles being near the explosive sources when they are used.

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Kona Kai Ola Project Acoustic Analysis

1.0 BACKGROUND

This report consists of a noise analysis of the Kona Kai Ola construction Project during the construction of the proposed 800 slip harbor expansion. Kona Kai Ola is designed to be built in Kealakehe, North Kona District, on the Island of Hawaii. An enlarged portion of the proposed preliminary concept plan of the Kona Kai Ola facility, which shows the harbor, (i.e., the proposed action of the Kona Kai Ola Environmental Impact Statement (EIS)) is provided in the map below, Figure 1. This figure is a part of the concept plan which is Figure D in the EIS. The objectives of this analysis were: a) to predict peak in-air noise levels on the adjacent coastline and above Honokohau Bay during the planned construction activities at the sites, b) to predict peak in-water noise levels in Honokohau Bay during the planned construction activities at the sites, and c) to analyze the impact of these in-air and in-water noise level on the marine mammals and sea turtles potential present during the construction.

In order to quantitatively complete the objectives listed above, the following seven steps must be completed: 1) representative source and receiver locations that adequately characterize the acoustic environment must be identified, 2) the source parameters (i.e., source levels, locations, etc.) must be identified, 3) the natural environmental parameters (i.e., air and water temperatures, geological structure, etc.) which control acoustic propagation representative of the entire year (since the process will potential take place over multiple years) must be identified, 4) the propagation, both air and water borne, must be properly executed to determine the resultant noise fields, 5) the details of the potentially present marine animals and sea turtles must be identified and their normal distribution and behavior quantified, 6) animal disposition and noise field occurrences must be integrated to determine or estimate the potential exposure to acoustic energy that the animals receive, and finally 7) estimated animal exposure must be compared to the standard National Marine Fisheries Service (NMFS) criteria to determine the level of impacts to the various species.

Five spatial positions were selected to document the predicted noise levels, three positions were terrestrial and two were just above the water (one near the harbor entrance and the other near the final channel buoy). Hereafter these five sites will be referred to as the receiver sites and they are shown in Figure 1 as red circles. For this figure only, "receiver site" is abbreviated as "RCV." Additionally, the seven modeled source locations are identified in this figure as green circles and abbreviated as "SRC."

The five receiver sites were selected so that a) the model results would predict in-air receive levels (RLs) on the closest beach point from any of the modeled source sites and b) the in-air and in-water RLs for two representative measurement sites were examined. Receiver site #1 is a beach site approximately 510 ft from source sites #1 and #7.

Receiver site #2 is the offshore location, which is in the middle of the harbor channel where it crosses the 5 fathom (30 ft [9.1 m]) isobath, which is about 840 ft (256.0 m) from source sire #1. Receiver site #3 is the beach site which is closest to source site #2, which is about 1,770 ft (539.5 m) away. Receiver site #4 is the beach site which is closest to source site #3, which is about 1,980 ft (603.5 m) away. Receiver site #5 is the final channel buoy, which is north of the channel near the 30 fathom curve (180 ft [54.9 m] isobath) and approximately 1,780 ft (544.1 m) from source site #1. Thus Receiver sites #1, 3 and 4 can be used to predict the in-air RLs at three beach locations, all of which are inside the proposed project site. Receiver sites #2 and 5 are at representative sites, which should be relatively easy to identify from shore.

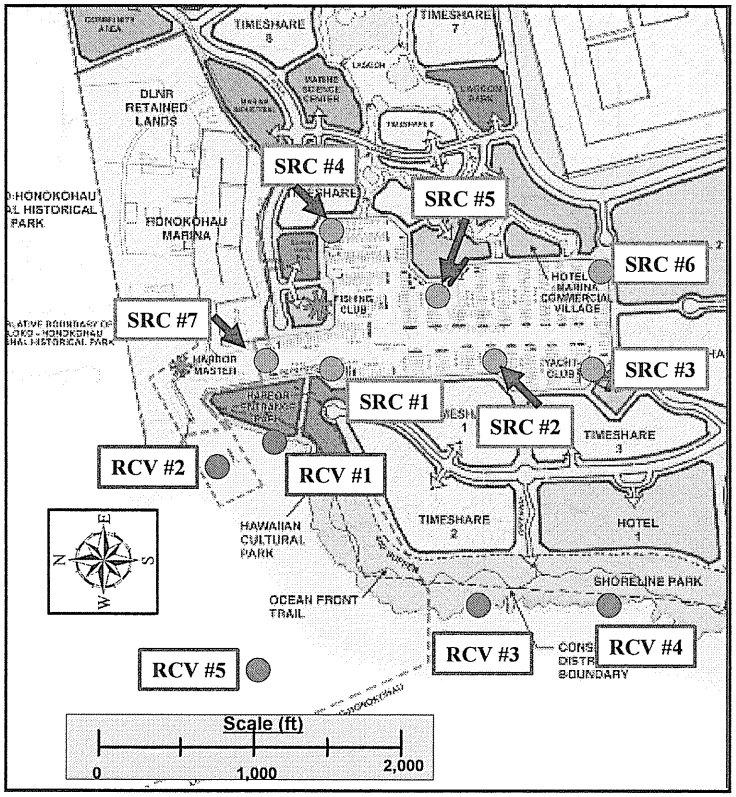

Figure 1 Map of Proposed Kona Kai Ola Site

There are four major potential noise-making processes in the scenario assumed for this analysis. They are: a) the explosives cutting/breaking of lava currently in what will become the 800 slip harbor as proposed for the proposed action in the Kona Kai Ola Environmental Impact Statement (EIS), b) the mechanical removal of the broken rock from the harbor by dredging, c) the drilling of holes prior to the installation of marine piles in the harbor and d) removal of the final solid-rock dam or berm which separates the new harbor from the old Honokohau small boat harbor's channel. All of the harbor explosive, dredging and pile construction, with the exception of that need to remove the final dam, will be completed before the removal of that dam. This analysis was directed toward arriving at the maximum RL that would be measured at each of the five receiver sites for each of these noise making evolutions. Essentially, each of these processes occurs separately and the analysis will not assume that any occur simultaneously. For example, when actual explosive operations are occurring, the area will be cleared for personnel safety, so dredging of the previous blast's debris will be stopped temporarily. Additional details on the characteristics of these noise sources can be found in Section 1.3 of this report.

In order to conduct this analysis, source levels for the in-air and in-ground/water high explosive detonations, drilling, and dredging must be established. These source levels have been documented by many measurements in the field for the drilling and dredging activities and are readily available. However, the source levels for the explosive work will have to be derived from standard equations, due to the unique configurations of their employment. By convention, source levels are designated at a range of one meter (m) (3.28 ft) from the noise source, which is assumed to be a point source (e.g., 1 m from the drilling site, 1 m from the center of the explosion, etc.).

After source levels for each process are established, the potential paths for sound transmission must be estimated from the point of origin to the five sites where the RLs are to be determined. For example, for the explosives, the in-air transmission paths consist of a set of ground paths from the approximately ten foot depth source to the grounds surface, then propagation via the air, to each receiver site. Simultaneously, the in-ground transmission paths consist of a set of ground paths from the approximately ten foot depth source to the ground/water interface, then water-borne propagation into the ocean. Each path has a loss of sound intensity associated with it and this loss is dependent upon many physical properties of the medium be it the air, soil, rock, sediments, or water. The establishment of a reasonable range for the physical properties of the propagation medium must be completed and input into standard, verified computer models in order to estimate the loss in sound level associated with each propagation path. For most areas of the world, a range of values is available to estimate the value of physical parameters by season of the year. For this analysis, published parameters for meteorological, geological, and vegetation cover were used as inputs into acoustic propagation models. Details of the required environmental parameters and the acoustic propagation models that use them are given in Sections 2.0 and 3.0 below.

Technical descriptions of the marine mammals and sea turtles potential present at the site are presented in Section 4.0. Here also is the description of the Acoustic Integration Model (AIM©) which was used to integrate the sound fields and the animal movements. Finally, the NMFS criteria as discussed in Section 1.2 is compared to the results from AIM© and reported in Section 5.0 of this report.

1.1 Units

A short discussion on units is in order to prevent confusion between "in-air" units and "in-water" units and "weighted" and "un-weighted" decibels. Decibels (dB) have by custom been used in the acoustic discipline in order to handle large differences in absolute values of pressures and energies. With the use of a decibel scale, transmission loss (TL) computations become "add and subtract" operations rather than "multiple and divide" operations, thereby simplifying calculations. Additionally, linear values which can cover many orders of magnitude are represented in scales which may cover one or two orders of magnitude. A "dB" is ten times the logarithm to the base ten of the ratio of the measured intensity or energy to a reference intensity or energy. In air the customary intensity reference is 20 micropascals (20 μPa) and in water the customary intensity reference is 1 μPa. To convert from in-air dB to in-water dB, simply add 26 dB. Thus a reading of 100 dB re 20 μPa is 126 dB re 1 μPa. Where "re" means "referenced to:". The same relationship holds for energy flux density (EFD) decibels. If in-air EFD levels are given, add 26 dB to get in-water EFD levels. Further, in order to match intensity levels with the sensitivity of the human ear, weighting is given to the dB readings as a function of frequency. The most common is "A-weighting" and it is indicated as "dBA.". If a letter after the dB is not given, then it is assumed it is an un-weighted sound pressure level; this is not always the case in literature, but it is in this report. Many noise measuring meters are designed to indicate noise levels in dBA (e.g., the "weighting" is built into the meter and should be indicated on the instrument). It is important to note what weighting is being used before comparing noise levels. Additionally it should be noted that the standard "A-weighting" is frequency dependent. In this analysis it was determined that the highest 1/3-octave band typically occurs for the sources at about 200 Hz. At this frequency the "A-weighting" is about 11 dB. This single value will be used conservatively throughout this report to change from "A-weighted" to unweighted values. For frequencies below 200 Hz, the weighting value increases (e.g., about 25 dB for 100 Hz) and for frequencies about 200 Hz the in-band energy level decreases. Therefore this assumption is conservative.

1.2 Established Injury and Harassment Criteria

The primary United States' law applicable to protecting marine mammals is the Marine Mammal Protection Act (MMPA).

The MMPA, subject to limited exceptions, prohibits any person or vessel subject to the jurisdiction of the United States from "taking" marine mammals in the United States or on the high seas without authorization. "Taking" includes harm or harassment. Section

101(a)(5) of the MMPA directs the Secretary of Commerce to allow, upon request, the incidental (but not intentional) taking of marine mammals by U.S. citizens who engage in a specified activity (exclusive of commercial fishing) within a specified geographical region if certain findings are made and regulations are issued. Permission may be granted by the Secretary for the incidental take of marine mammals if the taking will: 1) have a negligible impact on the species or stock(s); and 2) not have an immitigable adverse impact on the availability of the species or stock(s) for subsistence uses. Regulations must be issued setting forth the permissible methods of taking and the requirements for monitoring and reporting such taking.

The term "take" as defined in Section 3 (16 United States Code [USC] 1362) of the MMPA and its implementing regulations means "to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal." The term "harassment" means any act of pursuit, torment, or annoyance that has the potential to:

- Injure a marine mammal or marine mammal stock in the wild (MMPA Level A harassment); or
- Disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering (MMPA Level B harassment).

The MMPA was modified slightly by the National Defense Authorization Act (NDAA) of 2004, but for the purposes of the explosive sources in this document, the specific criteria and calculation techniques utilized in the *U.S.S. Seawolf* and *U.S.S. Churchill* FEISs' (DoN 1998 and 2001) are replicated here.

In-Water Impulsive Source Criteria

The *U.S.S. Seawolf* and *U.S.S. Churchill* FEISs' (DoN 1998 and 2001) methodology for determining the potential for effects on marine mammals resulting from the use of explosives in water has been formally accepted in published Final Rules by NOAA Fisheries/National Marine Fisheries Service (NMFS). Currently, these criteria are based on the best science that is available from all in-water and terrestrial experiments and extrapolations. From these, the following dual criteria for harassment (MMPA Level B incidental takes) are established:

- The onset of Temporary Threshold Shift (TTS) is estimated to occur when the highest 1/3-octave band RL at an animal exceeds 182 dB re $(1\mu Pa)^2 \cdot s$ (EFD), or
- The onset of Temporary Threshold Shift (TTS) may occur when an animal is exposed to a 12 pounds per square inch (psi) or greater peak pressure.

For plane waves, EFD is the time integral of the squared pressure divided by the acoustic impedance of sea water. It is assumed the acoustic impedance is the same throughout the sound field. EFD has units of Joules per meter squared or pound force per square inch. In-water EFD levels are by convention expressed in "dB re $(1\mu Pa)^2 \bullet s$" (Urick, 1983), while in-air EFD levels use the reference "dB re $(20\mu Pa)^2 \bullet s$."

The dual Level B incidental harassment criteria will be identified as the "TTS-Energy" and "TTS-12 psi" criteria, respectively, hereafter. The "TTS-Energy" criterion applies to the received signals in the highest 1/3-octave band produced by a source. For mysticetes (i.e., baleen whales, see glossary), 1/3-octave bands above 10 Hz are considered, while for odontocetes (i.e., toothed whales/dolphins, see glossary) 1/3-octave bands above 100 Hz are used. The "TTS-12 psi" peak pressure criterion effectively uses the pressure from all frequencies. The maximum range (or radius) from the source where these TTS criteria are met defines the zone of influence (ZOI) for incidental harassment (Level B) for a single explosion.

TTS was accepted as the Level B (i.e., "harassment" criteria) for the *U.S.S. Seawolf* and *U.S.S. Churchill* FEISs because the actual explosion planned for those tests were a one time occurrence and effectively, the potential "startle" reaction from a single explosion was not considered a "behavior" harassment. TTS was identified and accepted as a better metric of Level B harassment in those documents. The applicability of a similar assumption and utilization of TTS for the Level B criteria for this document can be questioned since a typical day of harbor excavation may consists of probably no more than 2 explosive events over a 12 hour period (i.e., per day assuming daytime construction only). However, the case can made that infrequent use of explosive precludes the same animal from being present (i.e., in the vicinity) for more than one blast; therefore, the use of TTS as the Level B criterion is reasonable.

The *U.S.S. Seawolf* and *U.S.S. Churchill* criteria also define dual-injury criteria (MMPA Level A injury) for marine mammals as follows:

- 50 percent Tympanic Membrane (TM) rupture.
- Onset of slight lung injury.

These dual Level A injury criteria will be identified as the "Injury-Energy" and "Injury-Positive Impulse" criteria, respectively, in this document.

The 50 percent TM criterion was based on experiments with terrestrial mammals, which had been exposed to detonations (in water). This recognizes that a "TM rupture *per se* is not necessarily a serious or life-threatening injury, but is a useful index of possible injury that is well correlated with measures of permanent hearing loss." The EFD associated with 50 percent TM rupture was established as "1.17 in-lb/in^2 (20.44 milli-joules/cm^2")." Note that in SI units this is equivalent to 204.4 J/m^2, or EFD level of approximately 205 dB re $(1\mu Pa)^2 \bullet s$, where specific impedance of water has been set equal to $\rho c = 1.5 \times 10^6$ $kg \bullet m^{-2} \bullet s^{-1}$.

The onset of slight lung injury for a small animal (e.g., a dolphin calf) has been calculated using the *U.S.S. Churchill* FEIS (DoN 2001) methodology and is indexed to 13 psi-ms for a 27 lb (12.2 kg) animal on the surface. This is the conservative case since the positive impulse needed to cause injury is proportional to animal mass and therefore larger animals require higher impulse to cause the onset of injury. The methodology used in the *U.S.S. Churchill* FEIS (DoN 2001) is usually referred to as the "Goertner modified positive impulse method" and two different time criteria are used to calculate the positive impulse at any range. The first is the time interval between the direct path arrival and the surface-reflected arrival from the explosion to the position of the animal. The other time interval is 20 percent of the lung volume resonance period for the animal's length/mass and it is calculated at the animal's depth. The lesser of these two time periods are used in the calculations as recommended by Goertner (1982). Since all of the explosions proposed in this document occur approximately 10-15 ft (3.0-4.6 m) below the surface in solid rock, there is no methodology to use the Goertner approach to calculate positive impulse. Thus this criterion is not applicable and can not be exceeded.

It should be noted that all of these impulsive criteria are for a single explosion. Methodologies have been devised to extend these criteria to multiple explosives (DON, 2004 and Federal Register 22Apr2004). Effectively, those criteria which involve energy determine the size of their zone of influence by summing the energy from subsequent explosions. However, since the explosion proposed here occur typically separated by six or more hours, it is very unlikely that the same animals will be present nearby. Therefore, this energy addition is not necessary.

The sea turtle safety range calculations used in the *U.S.S. Seawolf* and *U.S.S. Churchill* FEISs are not used here because these explosions are in rock, do not produce a bubble (and the subsequent lower frequency acoustic energy spectrum), expend much more of their energy in mechanical rock breaking, the explosion is distributed three dimensionally and partially vented to the atmosphere. Those calculations would be too conservative to reasonably represent this situation. For the purposes of this report, the dolphin potential impact levels are assumed adequate for sea turtles too.

In-Water Coherent Source Criteria

In-water coherent source criteria commonly in use today are based on studies which began to be published in 1997 and continue to this day. "Behavioral Responses and Temporary Shift in Masked Hearing Threshold of Bottlenose Dolphins, *Tursiops truncatus*, to 1-second tones of 141 to 203 dB re 1 µPa" (Ridgway et al. 1997) is one of the first of a series of comprehensive studies of the effect of underwater acoustic noise on marine mammals. During this study, researchers observed behavioral modifications and temporary shifts in the hearing sensitivity of bottlenose dolphins exposed to 1-second tones at frequencies between 3 and 75 kHz. More recent work (Schlundt et al. 2000) extended the data to 400 Hz, included work with beluga whales, and used masking noise to create a consistent ambient noise environment. The conclusions of these studies are that temporary shifts in the hearing levels of odontocetes were observed at the average

RLs of 195 dB.

A re-evaluation of the results in these studies has produced an as-yet unpublished (either in peer-reviewed scientific papers or as Regulator/NMFS-reviewed environmental compliance documents) estimate of 190 dB as a threshold for changes in behavior. Additionally, NOAA/NMFS is working to define and publish criteria for Level A and Level B harassment. However, those criteria are not yet available. Therefore, for the purpose of this analysis, the 190 dB change in behavior criteria will be assumed as an appropriate reference value representing Level B harassment sound pressure.

Current thought is that total received energy may be a more appropriate metric for determining the RLs at which "Change in Behavior," "Temporary Threshold Shift (TTS)" and "Permanent Threshold Shift (PTS)" occur. By using a total received energy approach, both pulse-length and multiple received pulses are accounted for. For cetaceans (i.e., whales, dolphins and porpoises – see glossary), the selected levels for these metrics that were used in the impact analyses are as follows:

Change in Behavior (Level B):	190 dB re $(1\mu Pa)^2 \cdot s$
Temporary Threshold Shift:	195 dB re $(1\mu Pa)^2 \cdot s$
Permanent Threshold Shift (Level A):	215 dB re $(1\mu Pa)^2 \cdot s$

In-Water Broad-Band (Non-Impulsive) Source Criteria

In-water impulsive source criteria commonly in use today are: a) Level A sound pressure level (SPL) for pinnipeds of 190 dB re 1µPa, b) Level A sound pressure level (SPL) for cetaceans of 180 dB re 1µPa, and c) Level B sound pressure level (SPL) for all species of 160 dB re 1µPa. The Level A criteria are commonly used for pile driving Incidental Harassment Authorizations (IHA) (e.g., Federal Register, 2007, Federal Register 2006a), while both Level A and B criteria are cited for pile driving and seismic exploration (airgun work) (e.g., Federal Register, 2006b, Federal Register, 2002). For this analysis, these criteria are used, assuming that they are for a one second equivalent signal.

Since several of the noises produced during the construct (e.g., drilling and dredging) are: a) broad-band signals, b) typically longer than 1 second in length, and c) non-impulsive in nature (i.e., that do not contain a shock wave like explosives), their equivalent energy source level will need to be calculated by summing their acoustic energy over the length of the signal using the equation:

$$SL(energy) = SL\ (pressure) + 10 * LOG\ (duration\ of\ the\ signal)$$

For example a hydraulic excavator with an in-air, A-weighted, pressure source level of 98 dBA re 20 µPa @ 1 m, may excavates for 10 seconds and the takes 20 seconds to reposition. Its equivalent in-water energy SL is 134 dBA re 1 μPa^2-s @ 1 m (i.e., 98 + 26 + 10*LOG(10s) = 98 + 26 + 10 = 134), assuming a perfect transfer of in-air energy into

the water.

In-Air Broad-Band Source Criteria for Pinnipeds

A conservative estimate of SEL at which TTS may be elicited in harbor seals, California sea lions and northern elephant seals has been determined to be 145 dB re $20\mu Pa^2$-s and 165 dB re $20\mu Pa^2$-s, respectively (Federal Register, 2007b). For this analysis, a Level A threshold for Hawaiian monk seals is assumed to be 165 dBA re $20\mu Pa^2$-s. Additionally, SEL of 100 dBA are identified as the disturbance (i.e., Level B) criteria for hauled out elephant seal, harbor seals, and California sea lions. Thus, a SEL of 100 dBA is assumed to be the Level B threshold for Hawaiian monk seals and other marine mammals. Additionally, this value will be used conservatively for sea turtles which are basking or beached. (Otherwise sea turtles are assumed to spend less than 1% of their time with their heads above water, so in-water thresholds should apply then.)

1.3 Planned Operations and Explosives Employment

During the proposed construction of the Kona Kai Ola 800 slip small boat harbor, there will be numerous sources of anthropogenic noise. For the purpose of this analysis, only the three loudest sources are examined. They are: a) explosive blasting of the harbor, b) mechanical dredging of the broken rock, and c) the drilling of piling hole. Numerous other sources will be present, including: jackhammers, vehicle, pneumatic tools, backhoes, etc, but these sources are all nominally 8-10 dB less in source level than the three selected above. The following is a discussion of the source level for each of these three sources.

Explosives

The excavation of the Marina Basin will employ blasting with a standard explosive (usually ammonium nitrate boosted with a petroleum based fuel). The rock to be blasted is drilled with 3" or 4"diameter holes to a depth of 10' to 20'. The holes are drilled on a grid spacing of 7' by 7' or 8' by 8' depending on the toughness of the material being removed and are filled with the explosive. Each hole is set to detonate in a pattern to most efficiently break up and remove the material to be excavated. Time delays on the order of milliseconds are used to realize the correct blast pattern and to minimize ground vibrations and air shock waves. Total weight of explosives used per drilled hole typically varies from 30 to 60 pounds, and for each blast ranges from 3,000 to 7500 pounds (Moffatt and Nichol, 2007).

The explosive is detonated near the top of the hole and burns downward at several thousand meters per second. While the shockwave precedes outward in all directions horizontally it essentially forms a downward beam vertically. The direction of this beam relative to the vertical is a function of the relative burn speed to the speed of sound in the material surrounding the ballast hole. Since the times of detonation of the individual holes are time delayed the pressures do not add and therefore in the far field because each shock wave has already passed and dissipated before the next hole is detonated. Therefore, the highest pressure achieved in any blast is no more than that created by a single hole of explosives. The material to be removed from the basin is on the order of 2.8 million cubic yards and if it all needs to be blasted to break it free of the bedrock. Therefore, it will take about 500 blast fields of 120 blast holes per field to complete the job.

The resulting acoustic energy from a blast is transmitted through the air, ground and water. For a single explosive in water, numerous tests have been performed to quantify the source level produced as a function of the Net Explosive Weight (NET). NET is defined as the equivalent weight of TNT that the explosive material represents. It was estimated that the largest explosive source used in this project will be 120 holes, with each hole containing 60 pounds NET. The worst case was assumed wherein the blast holes were in water. The resulting Source Level (SL) is found as follows from a formula given by URICK (1982) for in-water explosions as follows:

$$\text{Pressure} = 2.16 \times 10^4\,((\text{NET})^{1/3}/3.182)^{1.13}$$

This is the pressure produced by a single hole in pounds per square inch (psi) at a range of 1 meter (3.182').

$$\text{Pressure} = 2.16 \times 10^4\,((60)^{1/3}/3.182)^{1.13} = 27{,}296 \text{ psi} = 1.9 \times 10^{14}\,\mu\text{Pa}$$

$$\text{SL} = 20 \log P = 280.3 \text{ dB re } 1\,\mu\text{Pa @ 1m.}$$

This estimate of the source level is conservative because it assumed a single point explosion where if fact the explosive in a drill hole is spread out over 10' to 20'of depth.

While SL is a measure of the intensity in an acoustic pressure wave another parameter called Energy Flux Density (EFD) is also of importance in determining the effects on marine mammals.

For plane waves in sea water, EFD is the time integral of the squared pressure divided by the acoustic impedance of sea water. For simplicity it can be assumed the acoustic impedance is the same throughout the sound field. EFD has units of joules per meter squared or pound force per square inch. In-water EFD levels are by convention expressed in "dB re 1 μPa^2-s" (Urick, 1983). For a NET of 60 pounds the resulting total EFD is 245.6 dB re 1 μPa^2-s @ 1m. This value is also know as the Energy Source Level (ESL). The highest 1/3[rd] octave EFD is 235 dB re 1 μPa^2-s @ 1m for a frequency of 200-234 Hz. The total energy (EFD) for all 120 blast holes is 265 dB re 1 μPa^2-s and the highest 1/3[rd] octave is 255 dB re 1 μPa^2-s.

All of the above explosive source level calculation are for in-ground or in-water conditions. The actuality of the Kona Kai Ola site is that effectively all of the bedrock is

old lava flows that have numerous cracks and pockets throughout its structure. Core drill samples of the site show that effectively all rock at an elevation of 0.0 feet or below is essential filled with water. The in-air SL for an explosion just above a blast hole is estimated by: a) starting with the in ground SL, b) reduce it by the spherical spreading of the energy as it propagates upward through the rock (e.g., -7 dB), c) approximate the energy loss crossing the ground/air interface (e.g., -10 dB) and d) correcting for the normal in-air reference units (-26 dB). Therefore, the in-air explosive SL is:

$$\text{SL (in-air)} = 280.3 - 7 - 10 - 26 = 237.3 \text{ dB re } 1\,\mu\text{Pa @ 1m}$$

<u>Dredging and Rock Drilling</u>

Moffatt and Nichol Inc. the contractor designated to complete the harbor excavation provided in-air source levels for their rock drills and hydraulic excavators. The nominal, in-air SL value that were provided for these activities are 96 and 86 dBA re 20 μPa @ 1m respectively for the rock drills and the excavators. These values were measured in-air. Correcting these values to what the in-ground SLs are, is the reverse of the process above for explosives with one additional correction to remove the A-weighting (assuming a 200 Hz signal a 11 dB correction is added). Therefore their in-ground SLs are: 150 and 140 dB re 1 μPa @ 1m.

It should be noted that each source has two different source levels depending on the medium that the sound will be traveling through. The values shown here are based on the empirical formulae that have been derived historically for explosions in air and in water. Since the acoustic impedance of soil is similar to that of water, the empirical formulae for water are also used for the ground paths. For the water and ground paths, the empirical formulae for ordnance detonations were identified by Arons (1949) and repeated in Richardson (1995). For the air paths, the procedure in ANSI standard S2.20 was used.

As previously discussed in Section 1.2 of this report, under the "In-Water Broad-Band Source Criteria" sub-section, the duration for a single dredge haul is estimated at 10 seconds, with 20 or more second of repositioning time. Thus about 10 dB needs to be added to both dredging SLs to correct for their length.

Similarly, the drilling SLs need to be corrected for duration. The following information was provided by Moffatt and Nichol (Moffatt and Nichol, 2007):

> "Approximately 500 marina guide piles are anticipated for the 800-boat, 45-acre marina. Typical depth of pile is estimated to be 10 ft deep into the basin floor. The piles will need to be drilled and grouted in to place from a truck mounted drill rig (either staged on land or from a small barge). Drilling production rates are anticipated to be at a rate of approximately 3 vertical linear feet per hour for a 2 in. diameter hole, or 3 piles per day per

rig. If two rigs are assumed to be on site, the duration would be 84 working days assuming a 10 hour day; with four rigs, 42 working days, etc"

For the purpose f this analysis, it is assumed that there will be typically two rigs working throughout most of the project, therefore it will take about 84 days to complete the drilling. Also, it is assumed that these rigs are widely separated in the harbor and that their acoustics energies do not add. It is planned and assumed in this analysis that all drilling will be completed prior to the remove of the dam, thus no marine animals should be in the immediate vicinity of the drilling. But animals on the beach or just offshore could potentially be exposed for a period of time prior to moving away. A 600 s (or 10 minute) period of time was selected as a reasonable maximum period, during which an animal could be exposed before moving away. This would add 27.8 dB (i.e., 10* Log(600)= 27.8 dB) to the drilling source levels.

Table 1, is a summary of the unweighted, in-air and in-water/ground SLs used for the three examined source types for the remainder of this analysis.

Table 1: Estimated Source Levels

Source Type	Unweighted In-Air SL (pressure in dB re 20 μPa @ 1m) (energy in dB re 20 μPa^2-s @ 1m)	Unweighted In-Water/Ground SL (pressure in dB re 1 μPa @ 1m) (energy in dB re 1 μPa^2-s @ 1m)
Explosives	237.3 (peak pressure) 222.0 (total energy/blast) 192.0 (1/3 octave energy/blast)	280.3 (peak pressure) 265.0 (total energy/blast) 235.0 (1/3 octave energy/blast)
Rock Drilling	134.8 (peak pressure)	177.8 (peak pressure)
Dredging	107.0 (peak pressure)	150.0 (peak pressure)

2.0 MODELING METHODOLOGY

Acoustic propagation models were used to predict the in-air and in-water noise levels for each type of noise. In general, these models utilize various approaches (i.e., solutions or approximate solutions of the wave equation) to estimate the effects of the transmission medium and boundaries on an acoustic signal transmitted at a source and "heard" at a receiver. Typical environmental effects include attenuation, reflection, refraction and result in modification of the signal as it propagates to the receivers.

2.1 Airborne Transmission Modeling

The model used to estimate in-air acoustic propagation was the Navy Standard Comprehensive Acoustic System Simulation (CASS) / Gaussian Ray Bundle (GRAB) model (Keenan, 2000). This model is a range dependent program that computes the TL associated with the potential propagation paths between a source and a receiver. Gaussian Beam models have been demonstrated to successfully model the complex atmospheric sound propagation (Gabillet, 1993). The underwater acoustic model identified here was modified to account for the differences between air and water propagation.

TL is the loss in intensity of sound as it travels from the position of the event to the position of the prediction point. TL in air is greatly affected by temperature, humidity, wind speed and direction, and most particularly by obstructions and vegetation. Consequently, the TL can have a large variance depending on the aforementioned parameters. Likewise, in water, TL is affected by temperature, salinity, pressure, wind speed, and surface roughness.

Due to the variability of these environmental parameters, it was necessary to examine them both seasonally and diurnally. The details of those investigations are provided in Section 3.1, but for the purposes of understanding the overall modeling it should be understood that conservative values (i.e., cases that result in relatively low TL and higher RL at the modeled sites) were utilized throughout the modeling. It should be noted that the typical construction day begins at daybreak and continues for about 12 hours, completing at about 18:00 PM, local time. Although night work could continue under lighting, this analysis assumed all work occurred during daylight hours. Therefore nighttime environmental factors were not closely examined. However, a brief examination of them showed that relatively small changes in predicted TL may occur.

For the modeling reported on here, a single air radiosonde profile was selected for the numerous model runs. This profile was from the summer season (August). It was selected because it showed the strongest near surface ducting or trapping of acoustic energy near the ground. All other profiles showed more near surface warming which resulted in upward refracting of acoustic energy, and greatly reduced predicted levels at the modeled receiver sites. Effectively, for these other cases, any anthropogenic, near-surface noise rapidly refracts (bends) upward and propagates into the atmosphere with minimal energy returning to the ground at the receiver points.

Since the Navy Standard CASS / GRAB model is a range dependent model (i.e., it is able to incorporate the effects of new environmental data in the TL estimations from the source to the receiver), critical environmental data such as ground elevation were digitized on a grid with a resolution of approximately 000 yards (91.4 m).

2.2 Seismic (In-ground) Modeling

Noise propagated via the ground to the water

An analysis was performed to determine the TL of seismic energy transferred from the detonations of high explosives, via the ground and coupled into the ocean. The energy transferred from a detonation will produce a shockwave in the rock around the explosion. The energy in this shockwave while in the earth is called "seismic" energy. Unlike acoustic energy in air or water, both being transferred via a single wave mechanism, seismic energy is contained in two different wave mechanisms consisting of compressional waves (P-waves – see glossary) and shear waves (S-waves – see glossary). For the weathered surface layer on land (soil), the velocity of the P-waves are about 500 m/s in loose soil and about 2500 m/s in consolidated sands and sediment under the water, and about 4000 m/s in limestone (coral). For the basalt, encountered by the drilled cores of this site (MACTEC, 2006) the sound velocity was estimated at 5,300 ms (USGS, 1985 and Hamilton, 1980). Additionally, this basalt was found to have a vesicles volume percentage of between 2-10 % and an attenuation value of 0.02 dB/km.

For the acoustic modeling of the ground, the basic basalt acoustic parameters were used, but a nominal 5% vesicle volume value was used. The vesicles were assumed to be 100% sea water with a sound speed corresponding to that measure at the same depth from an offshore sound velocity profle.

As was done for air, the CASS/GRAB model was implemented to examine the ray-paths and transmission loss resulting from sound propagation through the lava as it proceeds to the ocean. Conservatively, the great variance in the seismic propagation was ignored. For example, a layer of "dark gray, poorly graded sand" encountered at a depth of about 60 ft below sea level was not modeled, not were the presence of air or gas vesicles in the basalt. The effect of ignoring these scattering mechanisms is to underestimate TL and thus conservatively estimate the sound field at any point.

The resultant TL is equally applicable to both pressure and energy calculations.

2.3 Modeling of Airborne Transmission into the Ocean

Propagation of acoustic energy from air into water has been by examined by numerous studies which have attempted to predict this propagation in the presence of waves, water-entrained bubble plumes, biologics, etc. In the simplified case of a flat (i.e., waveless) ocean, the most important parameter controlling air to water transmission is the relative difference of the sound speeds of air and water (Urick, 1983 and Richardson 1995). Effectively, because the speed of sound in water is nearly five times that of sound in air, only sound waves striking the ocean at very steep angle can penetrate into the ocean. The angle that separates the sound that penetrates into the ocean from that which does not, is called the "critical angle." Typically, this critical angle is about 11.5° from the vertical. This means that any sound striking the ocean from an angle greater than 11.5°, is almost entirely reflected off the oceans surface and back into the air. A very small portion of the energy may "effervesce" into the ocean, but this would only be a few percent of the total energy and it would be a greatly reduced level (i.e., 20-40 dB or more reduction in the level of the incident sound level).

It must be remembered that the above discussion is for an idealized calm, flat ocean. In the presence of waves, the normal vectors to the waves' surfaces (i.e., the vertical line which points away from the wave for that particular point on the wave's surface) vary over the surface of the wave and with the size and shape of the wave. This is analogous to the "glints" of sunlight seen on the ocean in the presence of waves.

For moderate sea states, typical in the vicinity of the Kona Kai Ola project site (i.e., sea states from 0 to 3, with wave heights less than 1.25 m (4 ft) (Bowditch 1995)), it is conservatively estimated that only about 10% of the in-air sound enters the water (McCormick, 1972). This is effectively a 10 dB reduction of the acoustic signal as it penetrates into the ocean at angles greater that the critical angle with the flat ocean. At higher sea states (i.e., sea states from 4 or 5, with wave heights 1.25 – 4 m (4-13 ft)), perhaps 20% of the in-air sound enters the water (i.e., a 7 dB reduction of acoustic energy). For even higher sea states such as can occur with high gale or hurricane winds, crashing waves and entrained air bubble plumes effectively limit sound transmission into the water.

2.4 In-Water Modeling

The Navy Standard Comprehensive Acoustic System Simulation (CASS) / Gaussian Ray Bundle (GRAB) model (Keenan, 2000) was also used to model in-water acoustic propagation. This model has been extensively tested and validated for in-water acoustic modeling, and as part of the Navy's Oceanographic and Atmospheric Master Library (OAML) it has be validated for frequencies as low as 50 Hz to over 100 kHz.

3.0 ENVIRONMENTAL AND SOURCE PARAMETERS

3.1 In-Air Parameters

The most critical environmental parameter in determining the atmospheric propagation is the speed of sound in the atmosphere for the Kona Kai Ola project site. The National Climatic Data Center (NCDC), a part of the National Oceanic and Atmospheric Administration (NOAA), maintains an archive of radiosonde data (NOAA, 2004) that includes all of the information required to calculate the sound speed in air as a function of altitude (i.e., altitude, temperature, dew point temperature, air pressure and wind speed and direction) for numerous site throughout the US.

In that database, the closest site in the Hawaiian Islands to the Kona Kai Ola site is the Hilo, Hawaii site. Radiosonde data were extracted for Hilo for the following months as representative of the seasons in parentheses:

February 2007	(winter),
May 2007	(spring),
August 2006	(summer),
November 2006	(fall).

From each month, two typical and representative day-time profiles were identified and used in subsequent analyses. Figure 2 shows the selected sound speed profiles, while Figure 3 is a close up of the lowest 1,000 m (3,281 ft) of those profiles. These sound speeds were derived from the NCDC radiosonde data using the equations identified by Cramer (1993). All data start at an elevation of 10 m (33 ft) because this is the elevation of the Hilo site. For this modeling analysis, it was assumed the trend of sound speed continued linearly to sea level and the lowest altitude sound speed slope was therefore extrapolated to an elevation of zero.

In Figures 2 and 3, all of the sound speeds generally show a decrease as altitude increases. This would cause acoustic energy to refract upwards. However, of the sound speeds also have a slight increase in speed for the elevations up to about 200 ft (61 m). This configuration could cause a near surface duct or trapping of sound. Conservatively, the August sound speed profile was used in all subsequent modeling since shows the strongest duct and it would provide the most acoustic energy arriving at the receiving sites. Combinations of wind, turbulence, and density differences and other scattering mechanisms in the air could allow acoustic energy in these other profiles to reach the receiver sites, but they would be expected to have been reduced by 5-10 dB or more from the August propagation which best allows energy to be trapped near the ground.

It should be noted that although these radiosondes are from the Hilo site, they appear to be fairly representative of the island of Hawaii.

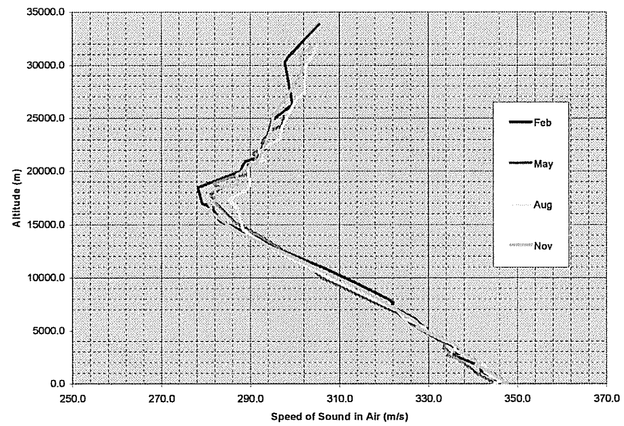

Figure 2 Sound Speed in Air for Hilo Site

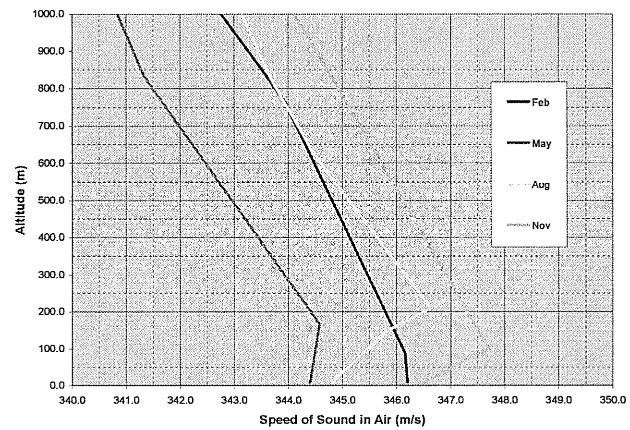

Figure 3 Enlargement of Sound Speed in Air for Hilo Site

The final in-air environmental parameter that needs to be addressed is the plant and tree ground cover for the area. For the modeled area three types of ground cover were assumed: grass, sand, and water. The ground attenuation for the grass, sand, and water categories was conservatively assumed to be zero. This appears to be a conservative value since there is some vegetation present in photographs of the area.

3.2 Seismic Parameters

At the Kona Kai Ola project site, seismic propagation occurs in the following materials and at the listed speeds of sound used in this analysis:

Speed of sound in loose soil/sand:	500 m/s
Speed of sound in loose basalt rock and sand:	2500 m/s
Speed of sound in basalt:	5300 m/s

3.3 In-Water Parameters

The primary water parameters required for the CASS/GRAB acoustic modeling were the sound velocity profiles (SVPs), the bathymetric contours and the ocean surface conditions,

The SVPs were obtained from the Generalized Digital Environmental Model (GDEM), Web Version 3.0, Database Version 3.0 (GDEM, 2007). The site selected for these profiles was 19.3°N 157.0° W. Figure 4 shows representative SVPs for each of the four seasons, while Figure 5 provides an enlargement of the upper 500 ft (152 m) of ocean. Effectively the SVP is an iso-velocity sound speed in the shallow depths throughout most of the year.

The bathymetry used was hand digitized from National Oceanic and Atmospheric Administration (NOAA) charts available in the MAPTECH , Region 40 nautical chart pack. The bathymetry was hand digitized to a resolution of 100 m grid using the best charts available in the MAPTECH package.

The ocean surface parameter selected was a mild wind of 5-10 knots.

The in-water receivers are modeled at a depth of 10 ft (3.1 m).

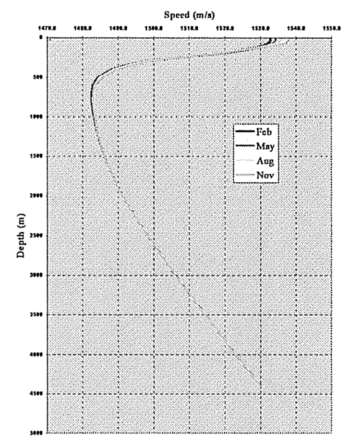

Figure 4: Sound Speed in Water for the Site

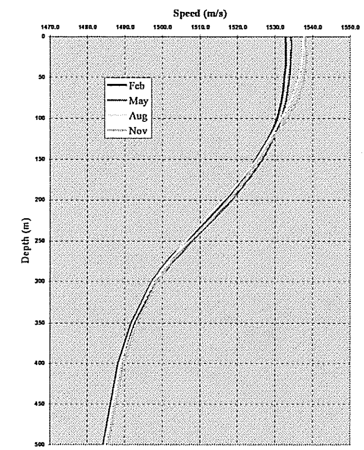

Figure 5: Enlargement of Sound Speed in Water for the Site

4.0 AIM MODELING

For the in-water integration the propagation of the acoustic energy from the explosive blasting and the distribution and movement of marine animals, the Marine Acoustics, Inc. (MAI) developed Acoustic Integration Model (AIM©) was used. In 1998, AIM© was endorsed by peer review at both the NMFS Acoustic Criteria Workshop and SURTASS LFA Sonar Scientific Working Group; additional details concerning AIM© can be found in "*Application of the Acoustic Integration Model (AIM) to predict and minimize environmental impacts*" (Frankel, et al., 2002). In 2006 -2007 a review was conducted of AIM by the Center for Independent Excellence at the behest of NOAA. The final report of that review was submitted to Dr. Stephen K. Brown (Stephen.K.Brown@noaa.gov) this year and is awaiting publishing.

AIM has the capability to use many standard acoustic propagation models. For this project the U.S. Navy standard Parabolic Equation (PE) model was selected for the in-water propagation. The results of this acoustic model had been compared with those produced by CASS/GRAB for several important depth cases, and the results were comparable (i.e., nominally within about 2-3 dB).

A listing of the marine mammals expected to visit the Kona Kai Ola project area along with their expected densities is provided in Table 5. The estimation of animal densities is a critical parameter in the estimation of potential impacts and it therefore receives a thorough review of the most current data available by the MAI biologists before the modeling is performed. There are two sources with slightly different density data for some species, which were used to derive the densities in Table 5. Typically, the average of the two densities was used. However, when only one source was available, it was used.

The Acoustic Integration Model © (AIM) uses simulated animals, called animats, in its simulations to predict acoustic exposure as a result of activities associated with the construction of the Kona Kai Ola project. The movements of animals is recreated in the simulation as an animat, and each animat monitors the received sound level. Different animals will experience the environment differently, as so do the animats. In this way, specific-species exposures can be predicted.

All of the movement parameters (e.g., speed, depth of dive) for each of the animats was taken from the existing document on Animal Behavior (Frankel and Vigness-Raposa 2006). The animats were limited to move within a defined subarea, to prevent the animats from moving away from the source of sound, and potentially reducing its predicted impact. That subarea was defined to the north by the 20° N latitude line and to the south by the 19° 10' N latitude line. The western boundary was 156°30' W and the eastern boundary was the coastline. A listing of the movement parameters used in this analysis appears in Table 2.

Table 2: Representative Marine Mammal Behavior Modeling

Species	Depth Range	Approx. Portion of Time in Depth Zone	Range of Course Changes	Average Speed
Bottlenose Dolphins	0 – 5 m	40%	0 – 30°	12 km/hr
	5 – 15 m	5%	0°	12 km/hr
	15 - 200 m	55%	0 – 30°	15 km/hr
Beaked Whales	0 m	10%	0 – 10°	5 km/hr
	5 – 120 m	5%	0°	5 km/hr
	120 - 1453 m	85%	0 – 30°	11 km/hr
Sperm Whales	0 – 10 m	12%	0 – 20°	2 km/hr
	10 – 300 m	5%	0°	2 km/hr
	300 - 1453 m	83%	0 – 10°	12 km/hr
Fin Whales	0 – 5 m	6%	0 – 20°	8 km/hr
	5 – 50 m	2%	0°	8 km/hr
	50 - 100 m	92%	0 – 10°	8 km/hr

Within this subarea, the depth preferences of each species was set to best approximate their natural local distribution

Humpback whales were limited to depths greater than 10 meters, to keep them in the water, and the offshore limit was 200 meters. The offshore depth limit is based on numerous reports that indicate that most whales are found within the 100 fathom line (Mobley et al. 1999; Mobley 2004).

In some cases, there are insufficient data to create animats for individual species. In these cases, it is necessary to "lump" data from similar species to create a composite animat. This was done for shortfin pilot whales, melon-headed whales and pygymy killer whales, which were modeled as "blackfish". False killer whales have been included in this grouping in the past. However, recent data indicate that false killer whales may dive less deeply than other species (Ligon and Baird 2001; Alves et al. 2006). Therefore, they were split into a separate group. All of these species are typically found in deeper water, and therefore these animats were programmed to remain in water deeper than 100 meters.

Bottlenose dolphins were limited to waters between 10 and 1,000 meters in depth. Bottlenose dolphins are typically considered shallow water animals (Cañadas et al. 2002), but the narrow shelves of Kona led to an increase in the allowable depth. Furthermore, the majority of Bottlenose dolphins in Hawaii were seen within the 1000 meter contour (Mobley et al. 2000; Baird et al. 2006a).

Most rough-toothed dolphins and, Risso's dolphins in Hawaii were seen in waters deeper than 1000 meters during aerial surveys (Mobley et al. 2000). However, this value was reduced to 500 meters, to allow for occasional forays into shallower water.

Kogia distributions were limited based on (Baird 2005) which found Kogia in waters between 600 and 3,200 meters. These limits were expanded to 400 and 4,500 meters to allow for variations in behavior.

Sperm whales were limited to 1,000 meters, as they are only found offshore off Kona.

Killer whales were allowed to roam from 10 to 4,500 meters, since they could potentially feed on any species.

Monk seals were allowed to move between 10 and 1,000 meters. They were limited from further offshore movement, since they are benthic feeders, and are known to dive to depths in excess of 500 meters (Parrish et al. 2002).

Beaked whales were limited to depths of 400 metes or deeper. Beaked whales in Hawaii have been seen in water 633 meters deep (Baird et al. 2006b), and this value was made slightly shallower to allow for occasional nearshore forays.

Striped and Spotted dolphins followed the normal Stenella behavioral pattern. However, for Kona, daytime and nighttime spinner dolphin animats were created. Daytime spinners were limited to water depths of 100 meter or less, while the nighttime spinner dolphin animats were restricted to water depths between 50 and 4,500 meters, which is when they forage offshore.

AIM model runs were not conducted for sea turtles, because of the lack of density values for these species. If they become available, these runs could be completed at a later date.

5.0 RESULTS

The results from the atmospheric propagation model include ray plots and TL plots for each source/receiver combination. A sample of ray plot is provided for an explosive source at source site #1 and receiver sites #5 (the final channel buoy) as Figures 4. The up-ward refracting rays are very obvious, but also the rays trapped near the ground can be seen for the few rays that start out at near horizontal angles.

Figure 5 shows a representative TL curve for the case of a source at source site #1 and received at receiver site #5. The TL curves for five different elevations are shown: sea level, 50, 100, 200 and 500 ft above sea level. Finally, this figure shows the TL for the completely airborne transmission path between the source and the receiver at sea level. The distance between source site #1 and receiver site #5 is 0.27 nm (0.5 km). TL for this path is found by: a) entering the figure at a range value of 0.27 nm, b) moving up to the intersection with the 0 ft elevation curve (the height of receiver #5), as is shown by the red dotted line, and c) reading the TL as shown by the solid red line. The resulting TL is 102 dB. This TL value and those for each source/receiver combination are provided in Table 3.

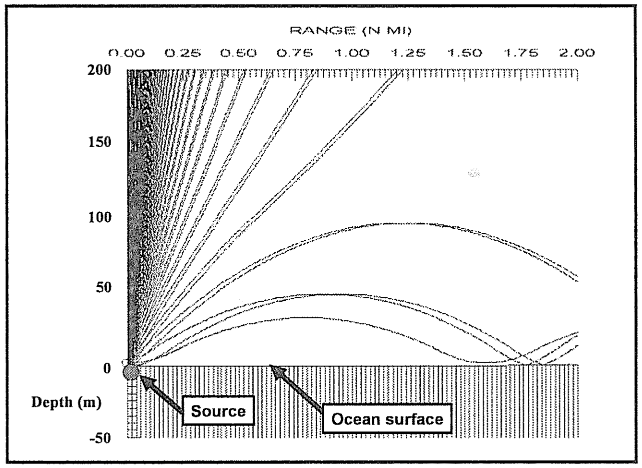

Figure 6: Ray Plot from the Explosives Source Site #1 to Receiver Site #5

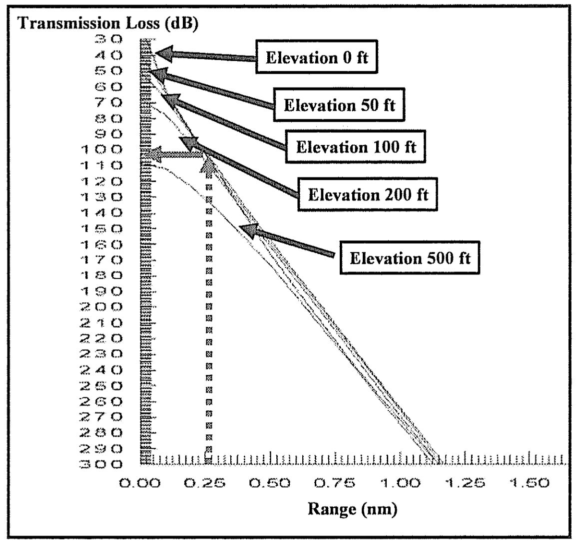

Figure 7: TL Plot from Source Site #1 to Receiver Site #5

Source	Receiver	TL (dB) to a Receiver in: Air	Water
1	1	70.0	55.0
	2	80.0	101.0
	3	110.0	89.0
	4	130.0	107.0
	5	102.0	86.0
2	1	95.0	77.0
	2	97.0	98.0
	3	105.0	87.0
	4	122.0	102.0
	5	116.0	112.0
3	1	138.0	112.0
	2	138.0	133.0
	3	117.0	98.0
	4	110.0	89.0
	5	149.0	138.0
4	1	100.0	81.0
	2	116.0	112.0
	3	140.0	114.0
	4	157.0	128.0
	5	138.0	114.0
5	1	108.0	87.0
	2	115.0	111.0
	3	128.0	104.0
	4	139.0	113.0
	5	130.0	124.0
6	1	145.0	116.0
	2	156.0	146.0
	3	152.0	120.0
	4	145.0	116.0
	5	175.0	155.0
7	1	70.0	55.0
	2	71.0	57.0
	3	117.0	98.0
	4	149.0	118.0
	5	109.0	91.0

Table 3: Transmission Loss for Source / Receiver Combinations

Table 4 provides the resulting RLs at each receiver site for each of the sources sites. The sources have been broken up by type (i.e., explosives, drilling, and dredging), and also by the location of the receiver at each site (i.e., the receivers for the three "In-Air" columns are located 1 ft (0.3 m) above the ground, while the "In-Water" receivers are 10 ft (3.0 m) deep in the water). The values in this table were derived by convolving the SLs from Table 1 with the TL from Table 3 and the correct conversions for reference pressure, and weighting.

		In-Air RL (dBA re 20 uPa)			In-Water RL (218 dB re 1 uPa)		
Source	Receiver	Explosives	Drilling	Dredging	Explosives	Drilling	Dredging
1	1	156.3	Amb.	Amb.	225.3	111.8	95.0
	2	146.3	Amb.	Amb.	179.3	65.8	Amb.
	3	116.3	Amb.	Amb.	191.3	77.8	61.0
	4	96.3	Amb.	Amb.	173.3	59.8	Amb.
	5	124.3	Amb.	Amb.	194.3	80.8	64.0
2	1	131.3	Amb.	Amb.	203.3	89.8	73.0
	2	129.3	Amb.	Amb.	182.3	68.8	Amb.
	3	121.3	Amb.	Amb.	193.3	79.8	63.0
	4	104.3	Amb.	Amb.	178.3	64.8	Amb.
	5	110.3	Amb.	Amb.	168.3	Amb.	Amb.
3	1	88.3	Amb.	Amb.	168.3	Amb.	Amb.
	2	88.3	Amb.	Amb.	147.3	Amb.	Amb.
	3	109.3	Amb.	Amb.	182.3	68.8	Amb.
	4	116.3	Amb.	Amb.	191.3	77.8	61.0
	5	77.3	Amb.	Amb.	142.3	Amb.	Amb.
4	1	126.3	Amb.	Amb.	199.3	85.8	69.0
	2	110.3	Amb.	Amb.	168.3	Amb.	Amb.
	3	86.3	Amb.	Amb.	166.3	Amb.	Amb.
	4	69.3	Amb.	Amb.	152.3	Amb.	Amb.
	5	88.3	Amb.	Amb.	166.3	Amb.	Amb.
5	1	118.3	Amb.	Amb.	193.3	79.8	63.0
	2	111.3	Amb.	Amb.	169.3	55.8	Amb.
	3	98.3	Amb.	Amb.	176.3	62.8	Amb.
	4	87.3	Amb.	Amb.	167.3	Amb.	Amb.
	5	96.3	Amb.	Amb.	156.3	Amb.	Amb.
6	1	81.3	Amb.	Amb.	164.3	Amb.	Amb.
	2	70.3	Amb.	Amb.	134.3	Amb.	Amb.
	3	74.3	Amb.	Amb.	160.3	Amb.	Amb.
	4	81.3	Amb.	Amb.	164.3	Amb.	Amb.
	5	51.3	Amb.	Amb.	125.3	Amb.	Amb.
7	1	156.3	Amb.	Amb.	225.3	111.8	95.0
	2	155.3	Amb.	Amb.	223.3	109.8	93.0
	3	109.3	Amb.	Amb.	182.3	68.8	Amb.
	4	77.3	Amb.	Amb.	162.3	Amb.	Amb.
	5	117.3	Amb.	Amb.	189.3	75.8	59.0

Table 4: Estimated Received Levels

Notes: The estimates of Ambient Noise Levels are 55 dB re 20 μPa in-air and 55 dB re 1 μPa in-water

It should be noted at this point that in some cases the above method of calculation will result in a RL that is below the ambient noise level. For simplicity, the overall average ambient noise level for this document are assumed to be 55 dB re 20 μPa for the in-air case and 55 dB re 1 μPa for the in-water case. In Table 4, when the received signal is below these ambient noise level estimates a value of "Amb." is entered on the table, implying that the noise is hidden in the background noise.

As can be seen in Table 4, all RL values for all of the in-water RLs for the explosive sources are below even the MMPA Level A criteria in Section 1.2, which is: a) about 165 dBA for the in-air case, b) an equivalent to about 218 dB re 1 μPa for the explosive in-water case, and c) 180 dB for the non-explosive in-water case. However, the in-air explosive Level A threshold is almost reached for the very short-ranged situation (e.g., sources #1 and 7 to receivers #1 and 2). Additionally, there are many cases where the Level B criteria are exceeded. In Table 4, these cell are color coded red. Please note that the drilling and dredging activities result in fairly low RLs at the receivers, and are often at or below ambient noise.

The red colored cells show conditions where Level B takes could theoretically occur. However, it must be remembered that for a take to occur an animal must be present to receive the acoustic transmission. Further analysis with the AIM model will determine the likelihood of potential impacts occurring.

AIM Impacts Results

Table 5 below shows the results of the AIM model runs. As can be seen there is a negligible probability of any Level A takes of any species, even without any mitigation, because all of the values in the Level A column are "<0.0001" takes. Similarly, the probability of any Level B takes is negligible because the highest estimated Level B take value is 0.0136 (for 100 shots or 0.068 for all 500 shots [explosive blasts]) for humpback whales. However, a note of caution is in order. Since the modeling is based on average densities off the coast of the Island of Hawaii, it cannot predict an unusual occurrence such as a pod of Spinner dolphin that has come into the bay and remains there during a blasting event. While this is a very small probability for any one point in time, it still does happen. If this scenario occurred as a blasting shot was detonated, Level B takes could occur. Therefore, mitigation should be in place to ensure a detonation does not occur unless the bay has been visually observed to be clear of mammals.

Table 5: Acoustic Impact on Marine Mammals

SPECIES (Common name)	DENSITY Animals / km^2	Level A Takes # per 100 shots	Level B Takes # per 100 shots
Blainville's beaked whale	0.00010	<0.0001	<0.0001
Blue Whale	0.00000	<0.0001	<0.0001
Bottlenose dolphin	0.00058	<0.0001	<0.0001
Bryde's whale	0.00019	<0.0001	<0.0001
Cuvier's beaked whale	0.00034	<0.0001	<0.0001
Dwarf sperm whale	0.00714	<0.0001	0.0004
False killer whale	0.00010	<0.0001	<0.0001
Fin whale	0.00000	<0.0001	<0.0001
Fraser's dolphin	0.00417	<0.0001	0.0002
Humpback whale	0.26940	<0.0001	0.0136
Killer whale	0.00014	<0.0001	<0.0001
Longman's beaked whale	0.00041	<0.0001	<0.0001
Melon-headed whale	0.00165	<0.0001	<0.0001
North Pacific minke whale	0.00000	<0.0001	<0.0001
Pantropical spotted dolphin	0.03040	<0.0001	0.0014
Pygmy killer whale	0.00449	<0.0001	0.0002
Pygmy sperm whale	0.00291	<0.0001	<0.0001
Risso's dolphin	0.00241	<0.0001	0.0001
Rough-toothed dolphin	0.00488	<0.0001	<0.0001
Sei whale	0.00000	<0.0001	<0.0001
Short-finned pilot whale	0.01930	<0.0001	0.0009
Sperm whale	0.00080	<0.0001	<0.0001
Spinner dolphin **	0.02565	<0.0001	0.0012
Striped dolphin	0.00310	<0.0001	0.0002
Hawaiian monk seal	0.00000	<0.0001	<0.0001

6.0 CONCLUSIONS

The variability of the modeled/predicted RLs at the receiver sites are directly dependent on the modeled TL (i.e., the variability of the sources levels for each type of source is minimal). In conducting this analysis, the best available scientific, environmental, geologic, and meteorological data were obtained and used to calculate the TLs and subsequently to predict the RLs at the five receiver sites. Additionally, throughout this analysis, conservative assumptions were made. Therefore, the results presented here do not represent the full range of TL, which could occur, but an estimate of the typical nominal minimum TL (and therefore nominal maximum RLs) that can be expected for most days throughout the year. The results are not a "worst case" result, because there could be cases with stronger near-ground cooling or wind conditions which could increase the RLs, but days with these conditions would be infrequent and only represent an estimated 10-15 dB higher RL for the in-air case. Similarly, environmental conditions could greatly increase the TL, and effectively make the noise from the modeled sources indistinguishable from ambient noise. Therefore, great care will need to be exercised if or when comparing these results with *in situ* measurements. As a minimum, adequate environmental measurements (including radiosondes, sea state/wave height, wind speed, and direction, air and water ambient noise levels, etc) will need to be obtained in order to make comparisons to the modeled results presented here.

Table 6 provides a summary of the three construction noise sources examined, the thresholds used to evaluate Level A and B potential impacts for each propagation medium, and the approximate range within which the thresholds may be exceeded.

Table 6: Summary of Sources, Thresholds and Ranges Impacted

		Level A		Level B	
Source type	**Propagation Medium**	**Limiting Threshold Used**	**Approx. Range (m)**	**Limiting Threshold Used**	**Approx. Range (m)**
Explosives	Air	165 dB *	200	100 dBA ***	731
	Water/ground	205 dB *	200	218 dB **	300
Drilling	Air	165 dB *	< 1	100 dBA ***	15
	Water/ground	180 dB **	< 1	160 dB **	8
Dredging	Air	165 dB *	< 1	100 dBA ***	< 1
	Water/ground	180 dB **	< 1	160 dB **	< 1

Notes: * re 1 μPa^2-s ** re 1 µPa *** re 20 µPa

What this means to the Kona Kai Ola project is represented graphically in Figure 8. In this figure the estimated maximum extent of the Level A and B thresholds for both the in-air and in-water cases are shown overlaid on a map of the Kona Kai Ola project. The solid red line shows the 200 m Level A and B threshold for both the in-air and in-water case. It should be remembered that this line is for all potential blast events, when in actuality the 200 m radius is from an individual event only. Similarly, the Level B curves are presented. Also shown on this figure are red and dark blue dotted lines. The red line indicates that any blast occurring to the south (left on this figure) of this line will not project a pressure field where any sound level exceeds the threshold either in the existing harbor, or on the beaches. The blue line is for the Level B, in-water threshold. Effectively, nearly two-thirds of the harbor can be excavated without potentially impacting marine mammals or sea turtles.

In-Air Conclusions

The results in Section 5 show the estimated nominal, but conservative RLs for the modeled sites. These results for the individual source/receiver combinations show that the criteria for Level A impacts to marine mammals for either in-air or in-water conditions at the receiver sites were never exceeded. However, the high in-air receive level in the vicinity of the current harbor channel when the explosive source was at locations farthest north and closest to the existing harbor, indicate that, as one would expect, extreme caution must be taken within about 200 meters (656 ft) of the explosion. This condition mandates that a safety range out to at least 200 meters (656 ft) of the

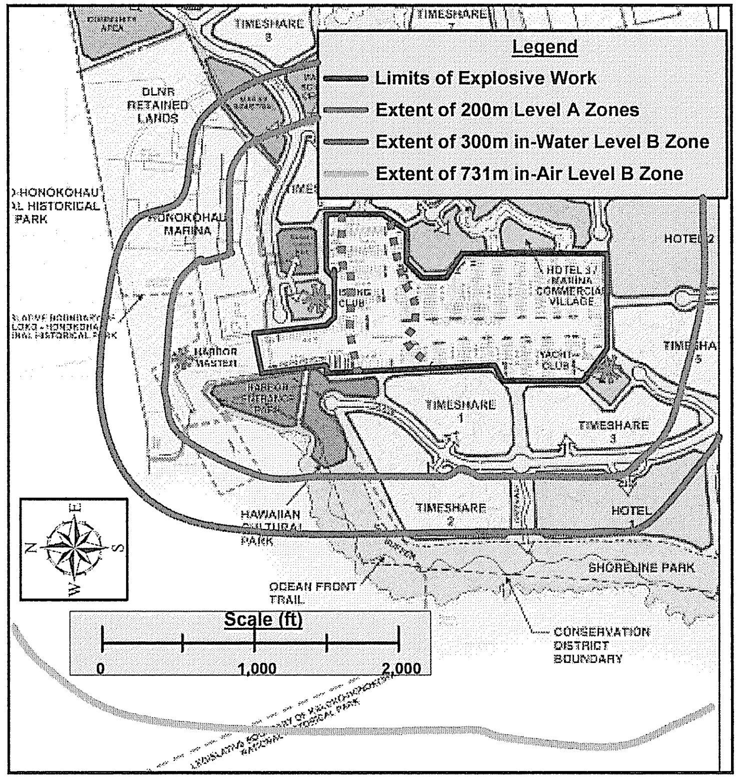

Figure 8: Threshold Level Curves Plotted on the Project

source be shown to be clear of all marine mammals and sea turtle prior to each blast to preclude potential Level A takes. Inside this range from an explosive blast, in-air Level A levels for marine mammals could potentially be exceeded.

Further, the in-air RLs for the explosive sources often exceed the assumed 100 dBA re 20 µPa threshold for Level B harassment of pinnipeds, other marine mammals or sea turtles. This typically appears to be true for ranges out to about 0.4 nm (i.e., 800 yds [731 m]). This threshold is nominally for pinnipeds, but it should be extended to marine mammals and sea turtles (when basking or beached) too. Therefore, an in-air safety buffer of at least 731 m from any explosive source is proposed, that should be maintained and found clear of marine mammals and sea turtle prior to any blasts. It should be noted that although a receiver site was not modeled specifically in the existing harbor, Figure 8 indicates that much of that harbor is within the range for Level A and B impacts for blasts conducted in the northern third of the new harbor and that extra care should be taken to ensure that no marine mammals or basking or beached sea turtles are in the existing harbor prior to any blast.

Although the possibility exist for Level B impacts to marine mammals, the marine mammal distribution and movement as predicted by the AIM model, indicates that this is very unlikely situation. Therefore, it is expected that there will be much less than 0.5 Level B takes due to in-air threshold, with or without mitigation, but the mitigation safety buffer must still be enforced to preclude the unlikely possibility of marine mammals or basking or beached sea turtles being near the explosive sources when they are used.

Finally, the in-air drilling and dredging noise rapidly attenuates to ambient level and the modeling indicates that it would be difficult to hear these noises at any of the receivers. Therefore, there contribution to the overall noise level outside of the construction site is negligible.

In-Water Conclusions

The results of the in-water thresholds are very similar to those for in-air. The possibility of a Level A in-water take only occurs for the explosive sources and when the animal is within about 200m (656 ft) of the explosion. This can only occur when the explosives are at the northern most position (i.e., near the existing harbor).

The most restrictive Level B explosive in-water threshold is the 12 psi (pressure) criterion. The modeling shows that it is only exceeded when a receiver is closer than 300 m (984 ft) from the explosive source. Thus, if the in-water safety buffer of 300 m is necessary to preclude Level B takes. Because of the harbor's position inland, much of this 300 m buffer occurs over land or in the very shallow water (i.e., less than 5 fathom, or 30 ft [9.1 m] deep), especially for the portions of the harbor farthest inland. Therefore, the possibility of potential impacts is small as predicted by the AIM model.

Also, even thought the drilling and dredging activities seem to have a better (i.e., less loss) propagation path through the basalt and potentially may be slightly easier to hear above background ambient noise, their levels remain within about 30 dB of ambient noise and approximately 50 dB below the 160 dB broad-band threshold.

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APPENDIX A

GLOSSARY OF TERMS

GLOSSARY

Acoustics: The scientific study of sound, especially of its generation, transmission, and reception.

Ambient noise: The typical or persistent environmental background noise present in the ocean.

Anthropogenic noise: Noise related to or produced by human activities.

Baleen: The filtering plates that hang from the upper jaw of baleen whales.

Baleen whales: The filter-feeding whales, also known as mysticetes.

Cetacean: Of or belonging to the order Cetacea, which includes aquatic mammals with anterior flippers, no posterior limbs, and a dorsal fin; such as whales, dolphins and porpoise.

Compression wave (or "P-wave"): is a wave in which the restoring force is provided by compression in the material through which the wave travels. P-waves are the mechanism that transfers sound through liquids and gasses and is one of the two mechanisms for the transfer of sound in solids.

Decibel (dB): A unit used to express the relative difference in power, usually between acoustic or electrical signals, equal to ten times the common logarithm of the ratio of the two levels.

Endangered species: Defined in 16 U.S.C. 1532 as any species that is in danger of extinction throughout all or a significant portion of its range (other than a species of Class Insecta designated as a pest). Federally endangered species are listed in 50 CFR 17.11 and 17.12.

Harassment: Under the Marine Mammal Protection Act, any act of pursuit, torment, or annoyance that has the potential to:

- Injure a marine mammal or marine mammal stock in the wild; or
- Disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering.

Hertz (Hz): The unit of measure of frequency in cycles per second. 1,000 Hz is usually referred to as 1 kiloHertz (kHz).

Impedance (acoustic): The product of density and sound speed.

Mysticete: Any of several whales having symmetrical skulls, paired blow holes, and plates of

whale bone (baleen plates) instead of teeth of the suborder Mysticeti. Filter-feeding whales, also referred to as baleen whales.

Odontocete: Any of the toothed whales (without baleen plates) having a single blow hole and asymmetric skull of the suborder Odontoceti, such as orcas, dolphins, and porpoises.

Otariid: One of three families of Pinnipedia having small but well formed ears (known as "eared" seals) including eared seals, sea lions, and fur seals.

Permanent threshold shift (PTS): The deterioration of hearing due to prolonged or repeated exposure sounds which accelerate the normal process of gradual hearing loss (Kryter, 1985), and the permanent hearing damage due to brief exposure to extremely high sound levels (Richardson et al., 1995b)

Pinniped: Of or belonging to the Pinnipedia, an order of aquatic mammals that include seals, sea lions, walruses and similar animals having fin-like flippers for locomotion. They are carnivorous and "haul out" on shore to have their pups.

Received level (RL): The level of sound that arrives at the receiver, or listening device (hydrophone). It is measured in decibels referenced to 1 micropascal root-mean-square (rms). Put simply, the received level is the source level minus the TLs from the sound traveling through the water.

Reflection: Process by which a traveling wave is deflected by a boundary between two media. Angle of reflection equals angle of incidence. (Richardson et al, 1995b)

Refraction: Bending of a sound wave passing through a boundary between two media; may also occur when physical properties of a single medium change along the propagation path (Richardson et al., 1995b).

Salinity: A measure of the quantity of dissolved salts in seawater. It is formally defined as the total amount of dissolved solids in seawater in parts per thousand (‰) by weight when all the carbonate has been converted to oxide, the bromide and iodide to chloride, and all organic matter is completely oxidized.

Shear Wave (or "s-wave"): is a wave in an elastic material in which the restoring force is provided by shear in the material through which the wave travels. Shear waves only propagate in solids.

SONAR: An acronym for SOund NAvigation and Ranging. It includes any system that uses underwater sound, or acoustics, for observations and communications. There are two broad types of sonar:

- **Passive sonar** detects the sound created by an object (source) in the water. This is a one-way transmission of sound waves traveling through the water from the source to the receiver; and

- **Active sonar** detects objects by creating a sound pulse, or ping, that transmits through the water and reflects off the target, returning in the form of an echo. This is a two-way transmission (source to reflector to receiver) and is a form of echolocation.

Sound pressure level (SPL): Twenty times the logarithm to the base 10 of the ratio of the pressure to the reference pressure, in decibels at a specific point. The reference pressure shall be explicitly stated. SPL is usually measured in decibels referenced to 1 micropascal (rms).

Sound speed: Sound speed is the velocity that sound waves travel through a medium. Sound speed through seawater is approximately 1,500 meters per second (4,920 feet per second). It varies with water temperature, salinity, and depth (pressure). Sound speed increases with increases in temperature and pressure (depth), and to a lesser extent with increase in salinity. This change in speed as sound travels through water causes the travel path to bend in the direction of lower velocity.

Sound speed profile (SSP): The sound speed profile (SSP) is a graphic representation of the sound speed versus depth of the ocean. These profiles vary with latitude, season, and time of day.

Source Level (SL): The sound transmitted into the water by a sound source, such as an active sonar ping. SL is usually measured in decibels referenced to 1 micropascal at 1 m (3.28 ft).

Take: To harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt any of these activities.

Temporary threshold shift (TTS): Temporary increases in threshold occurring after exposure to high noise levels, which can last from minutes to hours to days (Richardson et al., 1995b).

Transmission loss (TL): Energy losses as the pressure wave, or sound, travels through the water, the associated wavefront diminishes due to the spreading of the sound over an increasingly larger volume and the absorption of some of the energy by seawater.

Threatened species: Any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. Threatened species are listed in 50 CFR 17.12.

APPENDIX B

LIST OF ACRONYMS

LIST OF ACRONYMS

dB	Decibels
dBA	"A" weighted sound level
dB//1µPa@1m	Decibels referenced to one micropascal measured at one meter from center of source
CASS	Comprehensive Acoustic System Simulation
°T	Bearing in degrees True
EFD	Energy Flux Density
ESA	Endangered Species Act
FEIS	Final Environmental Impact Statement
ft	feet
GRAB	Gaussian Ray Bundle
HE	High Explosive
hr	hour
Hz	Hertz
kg	kilogram
kHz	kilo Hertz
km	kilometer
kt	knots (nautical miles per hour)
kyd	kiloyard
LF	Low frequency (100 – 1,000 Hz)
m	meter
MF	Mid-frequency (1,000 – 10,000 Hz)
ms	millisecond
MMPA	Marine Mammal Protection Act
NCDC	National Climatic Data Center
NDAA	National Defense Authorization Act
NEW	Net Explosive Weight
nm	nautical mile
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
psi	pounds per square inch
PTS	Permanent Threshold Shift
RL	Received Level
sec	second
SI	International System of Units
TL	Transmission Loss
TM	Tympanic Membrane
TTS	Temporary Threshold Shift
µPa	micropascal
USFWS	U.S. Fish and Wildlife Service
yds	yards
ZOI	Zone of Influence

Appendix U

Marina Harbor
Water Quality Study

By Moffatt & Nichol

KONA KAI OLA MARINA
HARBOR WATER QUALITY STUDY

Prepared for:

Jacoby Development, Inc.

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June, 2007

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1. INTRODUCTION

Jacoby Development, Inc. has selected Moffatt & Nichol (M&N) to develop and apply a numerical hydrodynamic and water quality model of the existing Honokohau Harbor and the proposed development. This new development, Kona Kai Ola, is an environmentally sustainable marina featuring a mix of uses including: visitor and resident-serving commercial enterprises, hotels and time-share units, marina services, and open space and community-benefiting facilities (such as public infrastructure improvements) in a pedestrian-friendly setting surrounding the marina and seawater lagoons. The proposed Kona Kai Ola Conceptual Master Plan includes a new 45-acre 800-slip marina that shares the entrance to the ocean with the existing Honokohau Harbor.

This report presents the development and calibration of a three-dimensional hydrodynamic and water quality numerical model of Honokohau Harbor, Kona Kai Ola and the surrounding coastal areas using a state-of-the-art numerical modeling system. Existing hydrodynamic and water quality conditions have been accurately reproduced with the numerical model, which indicated that the model can be used as a tool to predict the hydrodynamic and water quality conditions expected after construction in the new harbor system. A large number of future scenarios have been simulated with the numerical model in order to predict changes in water quality conditions after construction of the development. The model was also used to identify possible modifications to the conceptual master plan for the marina that could lead to acceptable water quality conditions of the new marina system.

2. WATER QUALITY AT HONOKOHAU HARBOR (1975-2006)

The historical data for specific water quality and hydrologic parameters for the Honokohau Harbor near the Kaloko-Honokohau National Historical Park, Hawaii are presented concisely in the following sections. The Harbor was built in 1970 and expanded in the late 1970's. Monitoring had been on-going for five years following the completion of the initial construction (1970-1975). The monitoring was performed with the purpose of investigating the resulting water quality conditions in addition to examining the colonization and ecological development within the Harbor. Because of the isolation of the Harbor from developments (absence of National Pollutant Discharge Elimination System-permitted dischargers (point source) and river/stream runoff (nonpoint source) within two miles of the Harbor), the Harbor provided a unique opportunity to "delineate valuable ecological cycles and describe important phenomena that may influence…coastal developments of this sort" (Bienfang, 1980). In short, baseline conditions were monitored and documented for future reference. Subsequent to these conditions, more recent studies have indicated that the Harbor's water quality has apparently improved since the post-construction survey. This conclusion is based upon increased dissolved Oxygen (DO)[1] for the temperature/salinity regime. Several benchmark parameters were used in this assessment to evaluate the DO improvements: ortho-phosphate (o-P)[2], nitrate-nitrogen (NO_3-N), ammonium-nitrogen (NH_4-N), Chlorophyll a (CHLa) and reactive Silica (Si).

The information collected and compiled by Bienfang (1980) and Bienfang and Johnson (1980) provide baseline information that will enable the State and other agencies to distinguish between background (pre-1980) and future man-made loadings/impacts. It is important to note that the studies (Bienfang, 1980 and Bienfang and Johnson, 1980) do not provide insight as to undisturbed conditions, as the harbor is a man-made entity in and of itself. These conditions only represent baselines in the sense that they describe conditions before the expansion conducted in 1978, and help to clarify and identify impacts after this time The results of the baseline assessment will be utilized to determine whether subsequent development in and near the harbor has resulted in degradation of the water quality since the expansion in 1978.

2.1 Harbor Waters

It was necessary to characterize water quality at specific sites throughout the Harbor in terms of vertical location in the water column, tidal cycle (when available) and time. Only small amounts of data were available for the Baseline and subsequent studies. Other complications precluded direct comparisons of the datasets[3], however, the relative changes in the water quality benchmarks are discussed. The applicable stations and benchmark concentrations for each study are presented in Appendix A (Figure A-1 through A-4 and Table A-1 through Table A-2, respectively).

[1]The DO degradation benchmark will be presented as % DO Deficit, the difference between the saturation DO for the specified temperature and salinity, and the measured DO.

[2] Orthophosphate is the dissolved form of phosphorous that is immediately available for bio-uptake.

[3] Bienfang (1980) presents datasets as arithmetic means with standard deviations for various depths (0.5 m from surface, 1.5 m and 3 m) at four Harbor sites and one outside the mouth of the Harbor (to represent oceanic conditions/control). OI Consultants (1991) presents results from seven Harbor stations and various outside stations for surface (0.5 m from the surface), mid-depth (variable) and bottom (variable) for low and high tides. Ziemann (2006) presents samples at eight stations throughout the Harbor for surface (0.2 m from the surface) and bottom (0.5 m above the bottom), without a tidal cycle designated.

2.1.1 *Dissolved Oxygen (DO)*

Baseline DO concentrations are of major concern as they show how the oxygen content was affected by the addition or subtraction of nutrients or other effects. Dissolved oxygen content is often used as an indicator of overall water quality. DO concentration is a response to various sources and sinks of which numerous relationships exist, including those listed in Table 2-1. Dissolved oxygen is depleted by oxidation of organic carbon, benthic oxygen demand, nitrification and respiration, and is replenished through phytoplankton production and reaeration at the surface.

Table 2-1: Summary of DO sinks and sources

DO SINKS (CONSUMERS):	
1.	Deoxygenation of biodegradable materials by bacteria and fungi;
2.	Benthic oxygen demand, utilizing oxygen in the upper, oxygenated (aerobic) layer of sediment;
3.	Nitrification of ammonia and organic nitrogen to nitrites and nitrates; and
4.	Respiration[4] by micro algae and macrophytes.
DO SOURCES (PRODUCERS):	
1.	Reaeration at the air-water interface, and
2.	Photosynthesis by the algae and macrophytes.

As a substance enters the water body, constituents either dissolve, settle, or are suspended in the water column for later dissolution, degradation or settling. Soluble constituents such as ammonium, may create "hot spots" of DO depletion, in which water column bacteria immediately seize the constituents as a food source, requiring large amounts of oxygen to degrade the materials. The strength of these materials is usually measured as biochemical oxygen demand (BOD). The BOD effect may be further qualified as carbonaceous or nitrogenous oxygen demands (CBOD or NBOD, respectively), depending upon the energy source in the waste (carbon or nitrogen) utilized by the consuming bacteria.

While "nutrient" effects are generally spoken of with respect to algal production, in reality, the mechanisms of nutrient loading and consequent degradation of the system are significantly different. Ammonium (NH_4) will quickly oxidize to nitrate, requiring 4.57 g-O/g-N, the theoretical oxygen demand for nitrification to NO_3,[5] exerting an immediate oxygen demand in the water column. Nitrate (NO_3) and ortho-phosphate (o-P)[6] are already oxidized, and do not exert

[4] Respiration is the consumption and decomposition of heterotrophs (animals, bacteria and fungi)/ rate of destruction of organic matter in the water column.

[5] Overall, 2 moles of O_2 are required for each mole of ammonia oxidized:

Oxygen required:	2 moles * 32 g-O/mole = 64 g
Ammonia to be oxidized:	1 mole * 14 g-N /mole = 14 g
	64/14 = **4.57** g-O/g-N

[6] "Phosphate" referred to in the Baseline study (Bienfang 1980) is actually ortho-phosphate, which is bio-available, inorganic phosphate.

an oxygen demand. However, they are plant nutrients and whether nitrogen or phosphorous is found to be the limiting factor in algal growth, eutrophication can become a problem. Eutrophication can often be referred to as "overfertilization" of a water body. Originally, this was used to describe the natural progression of a lake to a marsh to a meadow, however the term has been more predominantly used to describe the accelerated aging of a water body, whereby plant-growth within the water body exceeds the expected natural conditions due to human activities (Chapra, 1997)

Detrimental effects to water bodies due to eutrophication can include the excessive quantity of plant growth decreasing the water clarity and species naturally found in the water. In addition, the growth and respiration of plants can affect the oxygen and carbon dioxide levels within the water body. This can affect fish populations. The change in trophic state of the water body significantly affects the entire natural population within the water body, and in the case of Honokohau Harbor could have significant impacts on the coral populations present within the Harbor (Costa *et al*., 2000).

In classic eutrophication scenarios, the waters experience high "nutrient" levels, resulting in algae blooms, die-off, and sedimentation with subsequent unsatisfied benthic oxygen demand, leading to a DO collapse in the water column (EPA, 1985). In the Harbor water column, due to density stratification, algae that dies and falls out of, or is carried away from, the system remains out of the system. A review of the sediment samples[7] (Bienfang, 1980) reveals little organic matter on the bottom, indicating that algae do not die in sufficient numbers to build up an organic blanket on the bottom, and mineralization or denitrification are not contributing to the nitrate in the water column[8]. This is likely due to the high degree of flushing through the existing harbor. Thus, Harbor DO deficit is expected to be primarily from nitrification of $NH_4 \rightarrow NO_3$ and algal respiration.

In the Baseline Harbor study (Bienfang 1980) DO values are considerably lower than the respective DOSat[9] for the temperature and salinity at each station and depth. DO deficits range from 44% below DOSat in the Back Basin surface samples (0.5 m depth) to 24% below DOSat in the ocean samples (5 m depth)[10]. By 1991, the Harbor DO deficits indicate significant improvement; and in 2006, grab samples by Ziemann, corroborate this observation. Mid-Harbor

[7] % Organic materials in sediment cores were tested. Values were extremely low, ranging 0.79-2.81%, were determined to be primarily inorganic, and showed no spatial distribution or trends

[8] During mineralization and de-nitrification, organic nitrogen (from dead algae) is broken down at the soil: water interface. If oxygen in the bottom is in small quantities, NH_4 may be returned to the water column, oxidize to NO_3 and continue the cycle of DO demand and fertilization. In an anoxic bottom environment, N_2 may be formed during the process of de-nitrification and may result in N_2 bubbles leaving the water column through release into the air.

[9] DOSat = -139.34411 + (1.575701 x 105 / T) – (6.642308 x 107 / T2) + (1.243800 x 1010 / T3) – (8.621949 x 1011/T4) - Chlorinity[(3.1929) x 10-2) – (1.9428 x 101 / T) + 3.8673 x 103 / T2)]

where: T = deg. Kelvin
Chlorinity = salinity / 1.80655

[10] Hawaii WQ standards require minimum DO concentrations ≥ 75% of DOSat. Both the Back and Front Berthing Basins (stations 1 and 3, respectively) failed this standard in surface samples.

surface DO deficits have improved from a maximum of -44% (1980) to -26% (1991) to -15% (2006) with the greatest improvement seen towards the back of the Harbor.

2.1.2 *Nutrients (NH_4, NO_3 and o-P)*

A review of the Baseline nutrient data showed that soluble nutrients are variable throughout the Harbor. Maximum NO_3-N, o-P and NH_4-N concentrations were observed during ebb tide, surface samples of the Back Berthing Basin in the Baseline study (Bienfang 1980). Since, for all depths, nutrient concentrations are higher toward the back of the Harbor and become lower along Transect A-A' (Figure A-1) towards the ocean (as a result of tidal flushing/dilution), the source of nutrients appears to be in or near the back of the Harbor, corresponding to groundwater inflow.

Ammonium (NH_4)

Ammonium concentrations have decreased in the Harbor over time from the mid-Harbor maximum of 18.8 µg-N/L in the Baseline dataset (Bienfang, 1980) to a minimum[11] of <1 µg-N/L in the 2006 study (Ziemann 2006). Mean values in the Harbor (18.8 µg-N/L) and in the groundwater (14 µg-N/L) will each require < 0.09 mg O/L oxygen to fully oxidize $NH_4 \rightarrow NO_3$. These loads are insufficient to explain the high Harbor DO deficit calculated during Baseline or subsequent conditions. It is probable that the source of NH_4-N is not being characterized by the sampling sites (too variable or not near enough to the source), or it is loaded through an intermittent inflow, such as a rainfall/runoff event. It is also possible that other sources of oxygen demand are present.

Figure 2-1 shows the NH_4-N differences over the eight stations described in Ziemann (2006). It can be seen that in 1991, there is a significant increase in concentration between stations 4 and 6. This indicates that there could be an input into the system around this area. Suspected NH_4-N inputs into the Harbor include: septic sources, anchialine ponds and wildlife. From the historic data, inflows are also apparent at locations mid-Harbor and near the mouth. Mid-Harbor measurements (approximately between Ziemann (2006) stations 4 and 5) correspond to inflow from two restroom facilities: 1) between the Harbor Back and Front Berthing Basins and 2) north of the Harbor on the Honokohau Beach in the National Park (Hoover and Gold, 2005). The concentrations of NH_4 from these suspected sources are expected to be higher than that measured in groundwater; however, no corroborating inflow data has been collected at these sites.

[11] Ziemann (2006) provided only grab samples for the Harbor – one sample at each of the sites for the surface and bottom depths, so the single observations may not be representative of the Harbor water quality.

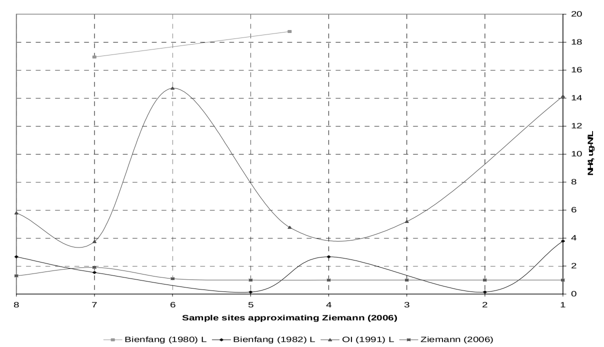

Figure 2-1: Ammonium surface concentrations

Nitrate (NO_3)

Nitrate concentrations have increased over time, where the lowest concentrations were measured in 1991 (OI, 1991) and the highest in 2006 (Ziemann, 2006). In addition to the nitrification of NH_4 as a source of NO_3-N in the Harbor, the dominant source of nitrogen in the Harbor is from groundwater[12]. Thus, characterization of this major source is critical to understanding the water quality evolution in the Harbor. One characteristic value for both NO_3-N and o-P in groundwater was provided in the Baseline study (Bienfang, 1980). Concentrations are significantly higher for groundwater than within the Harbor itself, but there are insufficient data to characterize the "groundwater signature" for the baseline conditions. Supplemental studies were consulted to provide additional characterizations of groundwater into the Harbor (Waimea Water Services, 2006 and Hoover and Gold, 2005). Marked variations in concentrations were seen across the sampled wells; however, using values nearest to the Harbor (Waimea Water Services, 2006), the values were fairly consistent with Bienfang (1980). In addition, the groundwater was studied by Hoover and Gold (2005) and nutrients were found to have a linear relationship with salinity. This corroborates the discussion by Oki *et al*. (1999) which describes the groundwater system with respect to oceanic inflow. This is further discussed in the hydrodynamics section. However, it suffices to say that a linear relationship of the nutrients found in the groundwater with salinity also corroborates values found by Bienfang (1980) and Waimea Water Services (2006).

If groundwater, which is the primary load of NO_3-N into the Harbor, is constrained to the average concentrations that were collected, the Harbor NO_3-N values would be expected to be lowered significantly because of dilution. Dilution was sufficient to explain the Harbor NO_3-N concentrations at most sites. Unexplained increases in NO_3-N in mid-Harbor suggest that additional NO_3-N is being "created" in the Harbor from nitrification of $NH_4 \rightarrow NO_3$ or loaded directly into the Harbor. Thus, the loading of NH_4-N into the Harbor must be higher than the groundwater NH_4-N measurements suggest, or there are additional unidentified loads of NH_4-N

[12] Bienfang (1980) states that coastal groundwater is high in NO_3 due to the geochemistry of the confining layer.

or NO_3-N flowing into the Harbor. Nitrate inflows are apparent in several studies at mid-Harbor stations (between Ziemann stations 4 and 5), corresponding to a restroom facility between the Back and Front Berthing Basins) and near the mouth (between Ziemann stations 6 and 7 (Ziemann, 2006)) as is shown in Figure 2-2.

Figure 2-2: Nitrate surface concentrations

Orthophosphate (o-P)

Phosphorus is one of several macronutrients required for the growth of marine organisms. In open ocean marine ecosystems, phosphorous is often present in low and, often limiting, concentrations for microalgal and bacterial populations. In the assessment of phosphorous from the various studies in the Honokohau Harbor, "phosphorous," "phosphate," "orthophosphate" and "soluble reactive phosphorous (SRP)" were measured. Identification of the analytical methods used for all samples indicated that the constituent measured, in all cases, was inorganic ortho-phosphate (o-P)[13].

Ortho-phosphate in the Harbor has decreased over time. The highest concentrations were measured in the Baseline study (Bienfang 1980 and 1982). The values decreased in 1991 and are at their lowest in 2006. These reductions in Harbor concentration imply that o-P loading has decreased, possibly due to improvements in nearby wastewater systems. An unidentified load of o-P is introduced near the Harbor mouth (between Ziemann stations 6 and 7), which is shown in Figure 2-3. The slight increases seen in Ziemann (2006) and OI Consultants (1991) are unattributable. They could be due to any number of factors; however, the fact that they do occur in two datasets indicates that it is not a data anomaly, but some sort of consistent source of nitrate and phosphate at this point. Stations 6 and 7 are located in different areas of the Harbor, with 6 being located in a narrow channel connecting the front and back berthing bays. Station 7 is located in a cul-de-sac of sorts immediately outside of this narrow channel. It could be that

[13] Orthophosphate is the dissolved form of phosphorous that is immediately available for bio-uptake.

there is a nutrient source near to this cul-de-sac, however it cannot be determined from this data what this source may be.

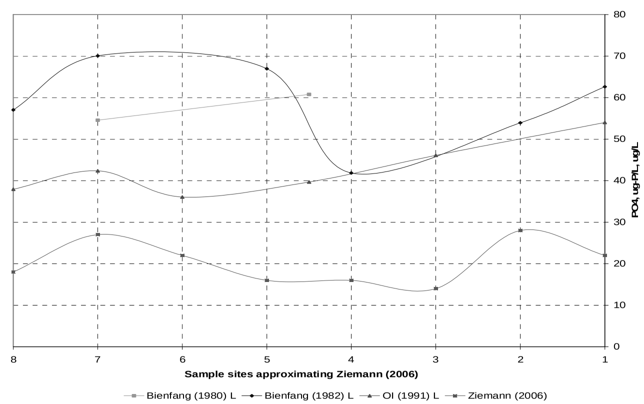

Figure 2-3: Phosphate surface concentrations

2.1.3 Supplemental Documentation for Source Loads

N:P Ratio

The nitrogen to phosphorous ratio (N:P)[14] is revealing as an indicator of pollutant origin. In nitrogen-limited waters (where nitrogen is the limiting nutrient), this ratio is expected to be <7.2:1 (Chapra, 1997). Waters where N:P>7.2:1 indicate that phosphorous is the limiting nutrient. Where nitrogen is severely limited, nitrogen-fixation[15] by blue-green algae may occur. In waters receiving wastewater effluent, the ratio is about 4 or 5:1 (Thomann and Mueller, 1987 and Chapra, 1997).

Chapra (1997) claims that typical marine waters and estuaries have an inorganic nitrogen to inorganic phosphorous ratio of about 2. However, in the waters offshore of Honokohau Harbor, the ratio of inorganic nitrogen to inorganic phosphorous is about 7.5 indicating that the system is fairly neutral as to its limiting nutrient.

[14] Literature states that the stoichiometric ratio of C:N:P taken up by algae during photosynthesis is 106:16:1 and the stoichiometric composition of the diatom and the typical green algae is O:C:N:P (109:41:7:2:1). (Chapra, 1997)

[15] This species of algae "fix" nitrogen directly from the atmosphere. This is considered a "nuisance" algae in managed waters, but may be essential in naturally nutrient-poor waters.

The N:P relationship for the waters within the Harbor and groundwater sources ranged in the region of 6:1-10:1[16] for all datasets (indicating nitrogen-limitation), except for the grab samples presented by Ziemann (2006), in which N:P ranged from 14-30 in surface samples and from 12-40 in bottom samples. The Ziemann (2006) data suggest that the system has become significantly phosphorous-limited since the 1991 intensive survey.

Bacteria

Enteric bacteria levels (total coliform, TC; fecal coliform, FC; and fecal streptococci, FS) in the water column are indicators of sewage contamination. The nature and source (human versus nonhuman) of the contaminants can be ascertained through measurements and ratios of the constituents. Waters that have ratios of FC/FS >1 are more likely to have been contaminated by human wastes. Bienfang and Johnson (1980) pointed out that possible sources of nitrogen and bacteria in the Harbor were from nearby "leaking/leaching septic sources and wildlife usage".

Except for the connecting channel between the Back and Front Berthing Basins (mid-Harbor), most stations indicated non-human origins. However, the increased bacterial counts and FC/FS ratios>1 in the Berthing Basins, indicates that sewage effluents are leaching from the septic facility near this location, because of the permeability of the lava walls within the Harbor (Bienfang, 1980).

2.1.4 Algal Responses (Chlorophyll a)

Algae (phytoplankton) affect the DO through photosynthesis and respiration. Diurnal DO measurements are usually made to verify and quantify the impacts of eutrophication. These data are not provided in Bienfang and Johnson (1980), but Primary Production was calculated and presented. Overall, the Harbor contains low phytoplankton biomass (measured as CHLa). CHLa is lowest in the brackish surface layer (0.5 m), increasing with increased salinity and warmer temperatures found at the lower depths. CHLa is highest in the mid-Harbor (Back Basin, approximately in between stations 4 and 5 of Ziemann (2006)) at the 1.5 m and 3.0 m depths, followed by the connecting channel (approximately between stations 5 and 6 of Ziemann (2006)) and falling off at the Front Basin (approximately at station 7 of Ziemann (2006)). In the Back Basin the measured values (weight and numbers) were about 28 times higher than those measured in both the Front Basin and the Ocean/control sampling stations (Bienfang, 1982). It appears that the phytoplankton select for the more quiescent conditions in the back basin at mid-depth (1.5 – 3.0 m depth) which optimizes salinity, temperature, light, and nutrients as observed in Bienfang (1982) and OI Consultants (1991). Pheophytin (a breakdown product of CHLa) was measured, yet provided no additional information or trends.

As a result of photosynthesis, algae strip CO_2 from the water column, resulting in increased pH, which is another indicator of eutrophication. Bienfang and Johnson (1980) verified that pH values were highest in samples taken at 3 m depths (corresponding to maximum CHLa measurements), but did not present data. Lowest pHs were found in the brackish surface samples (0.5 m depth), which is also not surprising due to generally low pH in groundwater.

[16] Bienfang (1980) discusses ratio N:P=15 within the groundwater, which is the ratio in the unconverted/non-normalized datasets (ug-atom/L), whereas the actual N:P ratio is approximately 7.

Regardless of tidal cycle or area of highest loading (Back Basin), the turbidity is greater than 90% transmittance, indicating that the high flushing is maintaining the water clarity (Bienfang and Johnson (1980)). Bienfang (1982) claims that the source of most of the turbidity within the water column is due to phytoplankton, and that post-expansion, the areas within the expanded harbor were most turbid. The clarity of the water allows penetration of light to deeper depths and acts as an enhancement to algal and coral growth.

3. HYDRODYNAMIC MODEL DEVELOPMENT

3.1 Overview of Delft3D Modeling System

Modeling was performed using the Delft3D modeling system. Delft3D, which was developed by WL| Delft Hydraulics, is a state-of-the-art integrated surface water modeling system based on a flexible framework capable of simulating two- and three-dimensional interactions between flow, waves, water quality, ecology, sediment transport and bottom morphology. The system gives direct access to state-of-the-art process knowledge, accumulated and developed at one of the world's oldest and most renowned hydraulic institutes. Delft3D consists of a number of well-tested and validated modules, which are integrated with one another.

The Delft3D FLOW module was specifically used to simulate the hydrodynamics of Honokohau Harbor. This module is capable of simulating two-dimensional (2D, depth-integrated) or three-dimensional (3D) unsteady flow and transport phenomena resulting from tidal and/or meteorological forcing, including the effect of density differences due to a non-uniform temperature and salinity distribution (density-driven flow). This model can be used to predict the flow in shallow seas, coastal areas, estuaries, lagoons, rivers and lakes. It aims to model flow phenomena where the horizontal length and time scales are significantly larger than the vertical scales. When the fluid is regarded as vertically homogenous with respect to temperature, salinity, and thus density, a depth-averaged approach is appropriate.

Delft3D-FLOW's system of equations consists of the horizontal equations of motion, the continuity equation and the transport equations for conservative constituents. The equations are formulated in orthogonal curvilinear coordinates. In curvilinear coordinates, the free surface level and bathymetry are related to a flat horizontal plane of reference. Flow forcing may include tidal variation at the open boundaries, wind stress at the free surface and pressure gradients due to free surface gradients (barotropic) or density gradients (baroclinic). Source and sink terms are included in order to model the discharge and withdrawal of water. Delft3D-FLOW solves the Navier-Stokes equations for an incompressible fluid, under the shallow water and Boussinesq approximations. In the vertical momentum equation, the vertical accelerations are assumed to be negligible and are neglected; this leads to the hydrostatic pressure equation.

3.2 Existing Conditions

3.2.1 Model Grid

The numerical model grid is shown in Figure 3-1. The model extent is approximately 9,700 m alongshore and 2,500 m cross-shore. Grid size is variable throughout the domain. The largest grid cells are located near the open boundaries with dimensions on the order of 180 m by 270 m, while the smallest grid cells are located at the existing harbor with a resolution of approximately 25 m by 25 m. The offshore boundary is located at a depth of roughly 650 m.

The vertical grid consists of layers bounded by two sigma planes, which are not strictly horizontal but follow the bottom topography and the free surface. Because the σ-grid is boundary fitted both to the bottom and to the moving free surface, a smooth representation of the topography is obtained. The number of layers over the entire horizontal computational area is constant, irrespective of the local water depth. A total of 8 layers are used in the model.

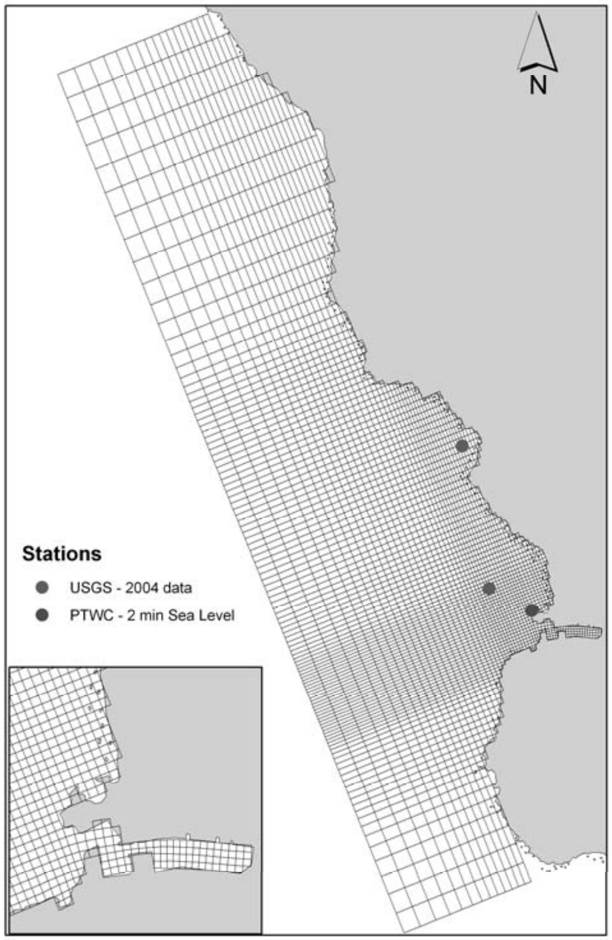

Figure 3-1: Model grid and location of available data

3.2.2 Model Bathymetry

The model bathymetry is presented in Figure 3-2. The near-shore bathymetry was created using data collected by the SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) system to a depth of -30 m MSL. At the harbor the bathymetry was created using the available navigation chart. Offshore areas were constructed from surveys collected by the National Oceanographic Service (NOS) of NOAA and available via their GEODAS system.

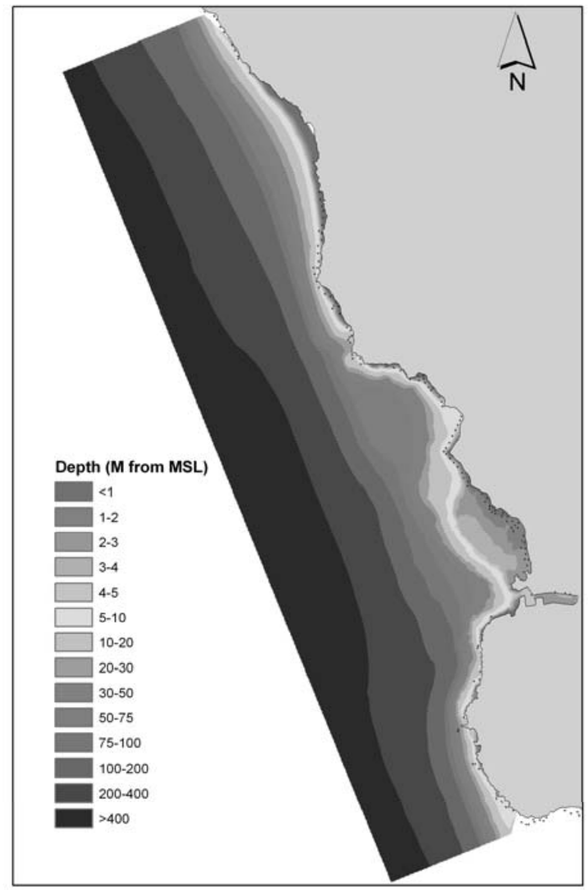

Figure 3-2: Model bathymetry

3.2.3 Boundary Conditions

The model was constructed with open-ocean forcing at its offshore boundaries. Detailed water level measurements along this boundary are not available. Instead, tidal constituents derived from available data can be used to construct a time series of water elevations. Water level measurements along the west coast of Hawaii are available at 4 stations (see Figure 3-3). Three of these gauges, Mahukona, Honokohau and Milolli are maintained by the Pacific Tsunami Warning Center (PTWC), and the gauge at Kawaihae is maintained by the National Ocean Service (NOS). Data at Mahukona and Milolli are on a 5 second interval and only available until 2004. Data at Honokohau are available on a 2-minute interval and available to the present. The detailed location of this station is presented in Figure 3-1. Data at Kawaihae are available on a 6-minute interval and are available to the present.

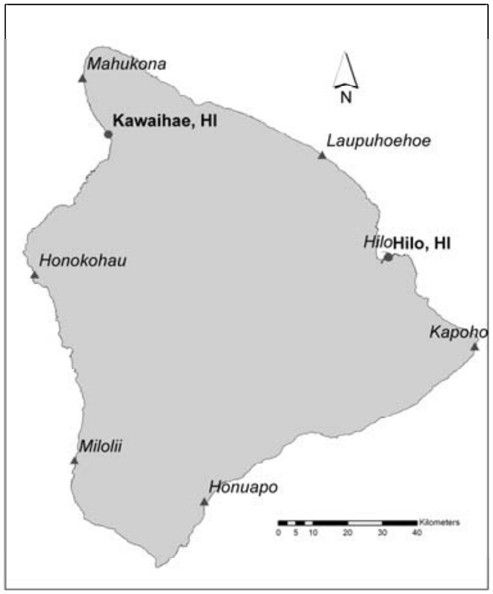

Figure 3-3: Available water elevation stations in Hawaii.

The two stations closest to the project location also measured more recent data. These stations, Kawaihae and Honokohau, were used to define the model boundary conditions. The distance between these two stations is approximately 50 km. One year of data was used to compute the 8 main tidal constituents at these two stations. These 8 tidal constituents are described in Table 3-1.

Table 3-1: Description of Tidal Harmonic Constituents

Harmonic Constituent	Speed (deg/hr)	Period (hr)	Description
O1	13.943	25.819	Principal lunar diurnal constituent
K1	15.041	23.935	Solar-lunar constituent
Q1	13.398	26.870	Larger lunar elliptic diurnal constituent
P1	14.959	24.066	Solar diurnal constituent
M2	28.984	12.421	Principal lunar tide
S2	30	12.000	Principal solar tide
N2	29.439	12.659	Monthly variation in lunar distance

The amplitude and phase of the 8 tidal constituents were extracted using the MATLAB toolbox "T-tide" (Pawlowicz *et al*., 2002). Values are presented in Table 3-2.

Table 3-2: Extracted Harmonic Constituents at Kawaihae and Honokohau

	Kawaihae (NOS)		Honokohau (PTWC)	
Harmonic Constituent	Amp (m)	Phase (deg)	Amp (m)	Phase (deg)
M2	0.200	58.2	0.196	45.0
N2	0.036	49.6	0.032	38.7
K2	0.020	55.6	0.016	36.2
S2	0.065	64.1	0.074	52.1
K1	0.158	226.3	0.154	219.4
P1	0.049	223.7	0.038	216.0
O1	0.089	214.0	0.083	209.8
Q1	0.013	204.3	0.012	198.5

The hydrodynamic model was forced by water levels at the offshore boundary and water level gradients at the lateral boundaries (north and south). These gradients were interpolated from the two stations presented in Table 3-2. Water levels at the offshore boundary consist of tidal predictions from interpolated tidal harmonic constituents of the two available stations. The phase difference for each constituent between these two stations was also computed. These stations are approximately 50 km apart while the model lateral boundaries are separated by 10 km; therefore a fifth of the phase difference was applied between the north and south model boundaries.

Salinity concentration and water temperature at the offshore boundary were selected as 34 ppt and 25 ºC respectively. These values are constant with depth and are based on the farthest offshore measured values presented in Ziemann (2006)

3.2.4 *Typical Conditions Assumptions*

The conditions modeled within the hydrodynamic and subsequently the water quality model are meant to represent typical conditions. The hydrodynamic model extents are not sufficient to simulate extreme events that would introduce significant surge or result in higher velocities such as tropical cyclones or tsunamis. It also does not include local wave effects or oceanic currents. The hydrodynamic conditions represented by the model include tidal elevations and include groundwater inflow, represented as point sources. The hydrodynamic model also incorporates typical heat flux conditions including relative humidity, air temperature, solar radiation, and percent cloud cover. Evaporation and conduction were also included in the computation. Each value entered into the heat flux model was taken as a typical day. One month of hourly solar radiation data was obtained from the Hilo weather station (Figure 3-4). A full year of daily atmospheric data was obtained from the Western Regional Climate Center. These data consisted of daily minimums and maximums (Figure 3-5 and Figure 3-6). The average minimum and maximum for the year were computed and used to extrapolate a daily time series of relative humidity and air temperature values. The extrapolated time series for these values are shown in Figure 3-7 and Figure 3-8 respectively. An average value of 250 $J/m^2/s$ was computed as the model input for solar radiation, and daily variations were computed by the model.

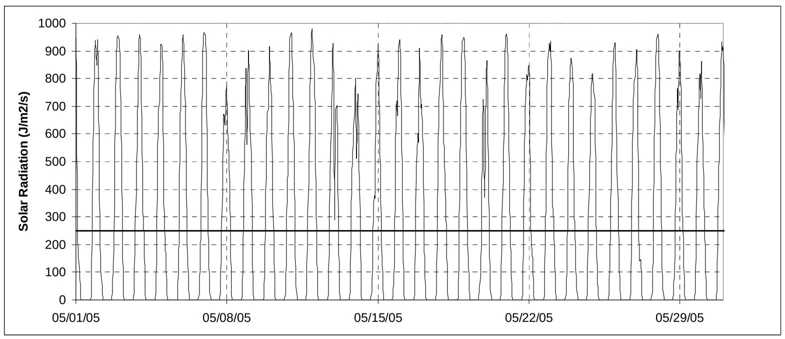

Figure 3-4: Solar Radiation

Figure 3-5: Maximum (red) and minimum (blue) air temperature

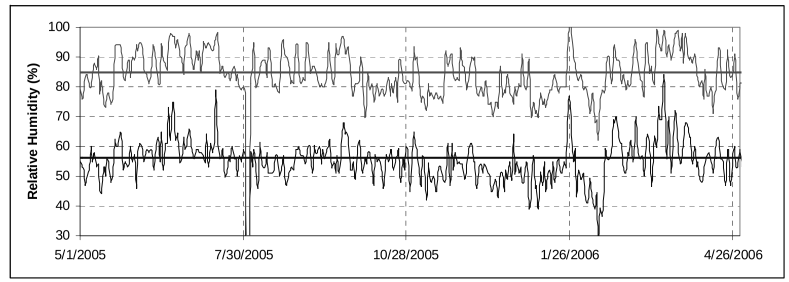

Figure 3-6: Maximum (red) and minimum (blue) relative humidity

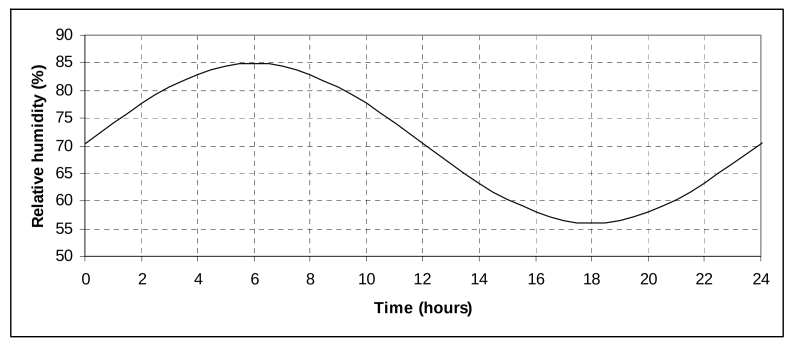

Figure 3-7: Average daily relative humidity

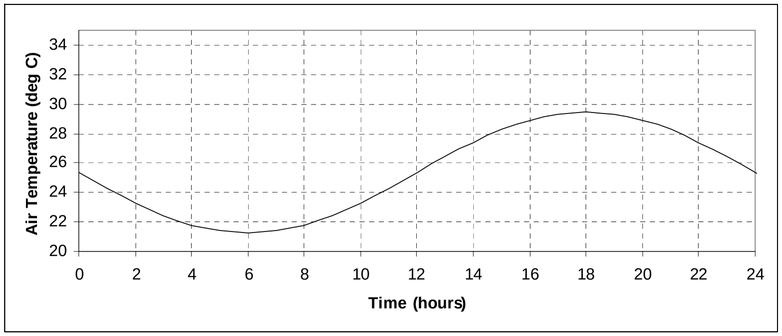

Figure 3-8: Average daily air temperature

3.2.5 *Water Level Calibration*

Model calibration was performed for May 2004 in order to coincide with the data collection period of Storlazzi and Presto (2005). The location of the stations for this study period is shown in Figure 3-1. Hourly values at the south station were provided by the National Park Service (NPS) covering the period 4/30/2004 to 10/30/2004. The data included depth, current speed and direction at 3 and 12 meters, significant wave height, wave period, temperature and salinity. Two-minute water level data from PTWC at Honokohau is also available for the same period.

Since tidal predictions were used to force the model at the open boundaries, the differences between measured and simulated water levels, are mainly due to differences between tidal predictions and water levels. As mentioned in previous sections, only 8 constituents were used to create the tidal open boundaries. The correlation coefficient between the PTWC water level data and the tidal predictions at this location is 0.93, and the Root Mean Square (RMS) error is 7 cm. These differences are the same as those obtained at the measurement location by comparing the measured and simulated water levels. Figure 3-9 shows time series of water levels from PTWC, USGS south station and simulated during May 2004.

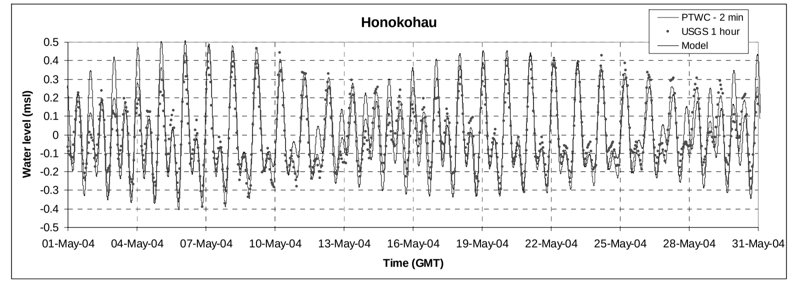

Figure 3-9: Water level data and modeled at Honokohau during May 2004

3.2.6 *Velocity Calibration*

Figure 3-10 presents simulated tidal flow fields at surface and bottom during peak ebb and flood on the 16th of May 2004. It can be observed from the figure that flood tidal currents are generally higher than ebb tidal currents, which is probably associated to the mixed tides of this area. In addition, the current reversal offshore is not present on the shallow area of Honokohau Bay, where the surface ebb tidal current is also moving north. The maximum tidal currents at the surface near the site of the USGS south measurement (see Figure 3-1) are in the order of 0.15-0.2 m/s, with an average value in the order of 0.07 m/s (Storlazzi and Presto, 2005 reported values of 0.09±0.07 m/s 3 m below the surface). In addition, the simulated primary flow direction at the USGS south location is approximately parallel to the shore, as presented in Storlazzi and Presto (2005). For example, the semi major axis of the largest constituent (M2) of the simulated tidal currents at the south location is approximately 0.05 m/s and is approximately parallel to the shore (varies between 25 and 15 degrees counterclockwise from North at surface and bottom).

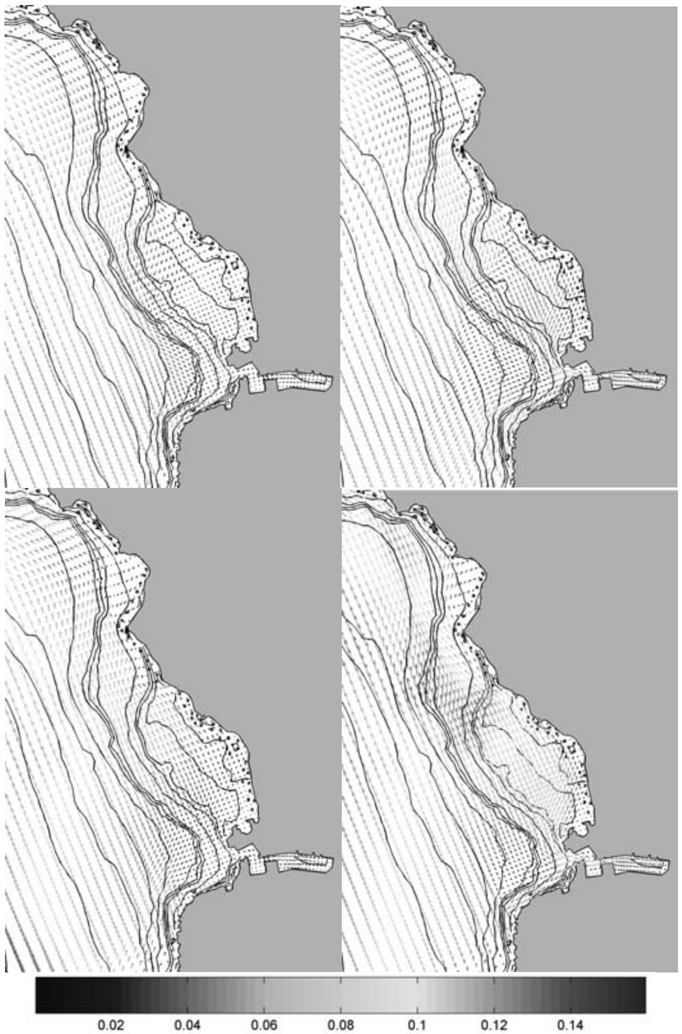

Figure 3-10: Simulated flow patterns during ebb tide (top) and flood tide (bottom) at bottom (left) and surface (right) layers on the 16th of May, 2004 (velocities in m/s)

The effect of the salinity gradients at the harbor are also observed in the currents. The surface current at the harbor entrance is always moving seaward while the current at the bottom is always moving landward. This is also observed in Figure 3-11 which presents the simulated velocity profiles at the harbor's entrance under peak ebb and peak flood conditions. It can be concluded from Figure 3-11 that the vertical distribution of velocities at the entrance shows high velocities in the surface moving seaward, and velocities entering the harbor in the bottom layers, as a consequence of the density stratification created by the brackish groundwater inflow into the harbor. Vertical distribution (with the position of zero velocity at a depth between 1.5 and 2.5 m) and magnitudes of the velocities are very similar to those described in Gallagher (1980) and the ADCP measurements presented in the Oceanit Laboratories (2006).

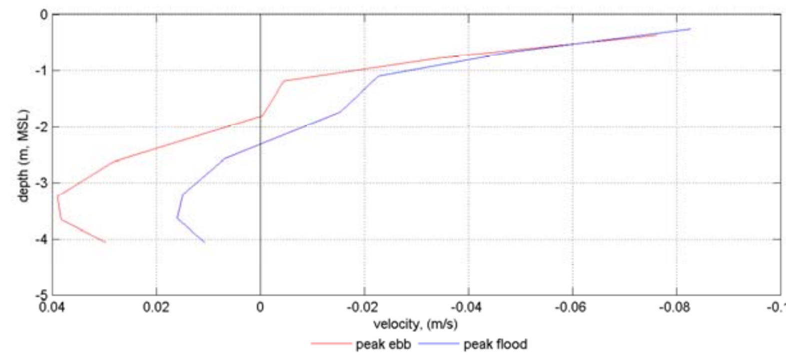

Figure 3-11: Velocity profile at harbor entrance

Figure 3-12 shows location of all cross-section and depth profiles extracted from the model and that are shown throughout the report. The cross-section of the existing harbor (Transect EH) is shown in red, while the cross-section of the future Marina is shown in purple (Transect NM). Figure 3-11 is taken from the harbor mouth point also shown in Figure 3-12.

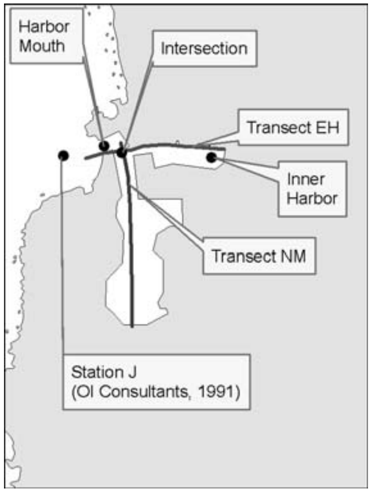

Figure 3-12: Locations of cross-sections and depth-profiles

3.2.7 Ground Water and Salinity/Temperature Calibration

The regional groundwater flow system with particular interest in the Kaloko-Honokohau National Historical Park area is described with detail by Oki *et al*. (1999). The study indicates that the groundwater flow system in the vicinity of the Park is part of the regional brackish-water transition zone. Oki *et al*. (1999) also assume that the main freshwater component of brackish water flowing through the Park is from subsurface flow originating from inland areas east of the Park. Brackish ground water forms by seaward flowing freshwater mixing with saltwater. The area of extensive mixing with saltwater extends upgradient from the Park. The brackish groundwater body overlies saltwater and extends to an estimated depth of about 50 to 100 feet at the inland boundary of the Park where the ground water is freshest. The study also indicates that because of the highly permeable offshore volcanic-rock outcrops, saltwater can easily enter the aquifer, and that a saltwater-circulation system exists beneath the freshwater lens. Saltwater flows landward in the deeper parts of the aquifer, rises, and then mixes with seaward-flowing freshwater. This mixing creates a brackish-water transition zone. In areas near the coast where saltwater mixes thoroughly with seaward-flowing freshwater, a freshwater lens may not form and brackish water may exist immediately below the water table. This is the case at the location of the existing harbor, and based on the available measurements it appears that the harbor was built in a location intercepting the layer of brackish water flowing seaward. A schematic view of the groundwater flow system is presented in Figure 3-13, which was taken from (Oki *et al*., 1999).

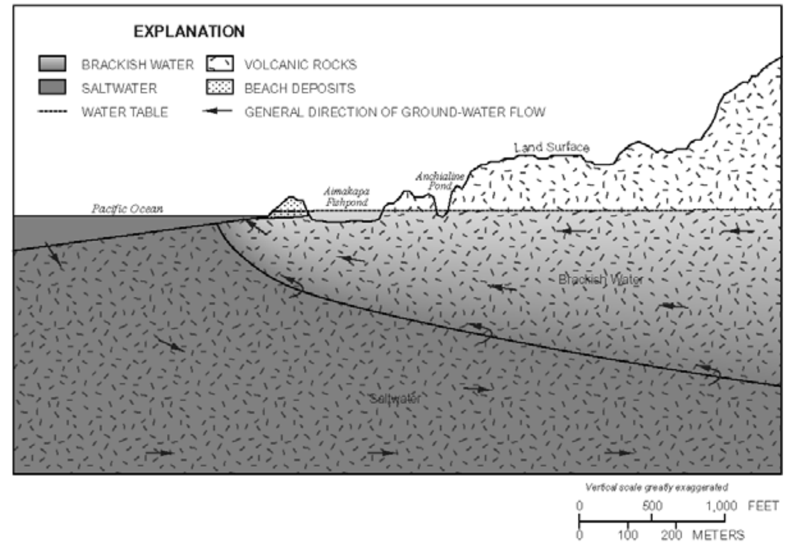

Figure 3-13: Schematic cross-section of the groundwater flow system in Kaloko-Honokohau National Historical Park, Island of Hawaii (Source: Oki *et al*., 1999)

The groundwater inflow into Honokohau Harbor has been reported in a number of studies as both freshwater and brackish water. The circulation within Honokohau Harbor is controlled by the influx of brackish groundwater, and determining the appropriate value for this source is imperative. Salinity and temperature distribution in the Harbor are controlled by both advection and dispersion effects. The advection component is dominated by the circulation in the harbor, which is a combination of tidal currents and currents generated by the two layer system created by the groundwater inflow. The dispersion part represents the scattering of a substance (salinity or temperature in this case) by effects of shear and diffusion. Therefore, it is necessary to estimate the rate of the brackish groundwater inflow into the harbor and the dispersion coefficient of the groundwater to correctly simulate, with the numerical model, the conditions at the Harbor.

<u>*Review of Available Information*</u>

This section summarizes the information obtained from some of the available studies regarding three different variables:

- Groundwater inflow into the harbor,
- Salinity and temperature profiles, and
- Flushing time.

Groundwater inflow

Bienfang (1980) described the water quality characteristics of Honokohau Harbor before the harbor expansion. The study mentions that the continual groundwater influx into the harbor, in the order of 1.5-2 million gallons of fresh water per day, produces harbor flushing rates six to ten times those calculated by tidal flushing alone. Bienfang (1980) based his estimate on the results from Cox *et al*. (1969) who said that the groundwater inflow in the Honokohau area is comparatively low because of the small recharge resulting from low rainfall and high evapotranspiration conditions of the area. Cox *et al*. (1969) estimated groundwater discharge in the Honokohau shoreline area to be a few millions gallons of freshwater per day per mile. Although in Bienfang (1980) it was mentioned that excavation of the harbor has displaced the natural discharge points in the immediate area landward, and that this displacement may also have caused enhanced discharge in this area, his oceanographic analysis still estimates the groundwater discharge into the harbor to be in the same order of the one suggested in Cox *et al.* (1969) along the shoreline.

A study also presented in 1980 by Gallagher, in same journal issue and under the same funding as Bienfang (1980), focused on the physical structure and circulation in the harbor. Using an extensive measurement campaign, this study concluded that the springs in the harbor were contributing on the order of 70 m^3/min (~27 mgd) of brackish water with an average salinity of 25 ppt during both ebb and flood phases of the tide. Gallagher (1980) also indicates that the bottom spring inflow rate is greater than the tidal exchange rate in the harbor, which is the cause of the pronounced layering and vigorous circulation. In addition, this study concluded that the flushing time of the harbor is in the order of 12-13 hours due to the existence of the strong flow of brackish water from the springs.

A recent study (Glenn, 2006) used infrared images and natural tracers to estimate the coastal groundwater discharges. Similar values were obtained from 3 coastal sites while at Honokohau Harbor the fluxes were estimated to be in the order of 20 times higher. Glenn (2006) indicates that this is likely the result of constructing the harbor at a level that intercepted the water table, resulting in "anthropogenically enhanced" flow. This study did not provide an estimate of the volume of brackish water flowing into the existing Harbor.

Salinity and Temperature Profiles

Salinity profiles from different studies indicate that under different tide conditions, the 29 ppt contour extends to a distance between 400 and 500 meters from the back Harbor wall. During the 1991 study by OI Consultants, this is observed for both high and low tide. Figure 3-14 shows the period where salinity and temperature cross sections were measured at Honokohau Harbor, (red shows the salinity and temperature cross sections at High Tide and green those at Low Tide). The salinity profiles are presented in Figure 3-15 and Figure 3-16.

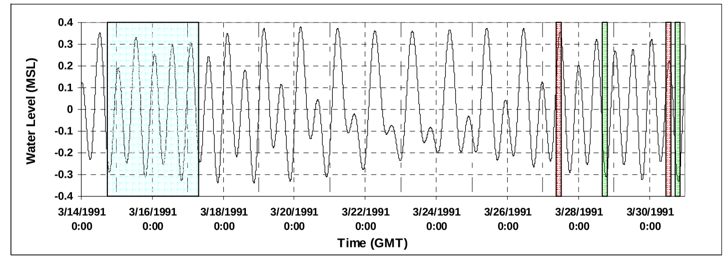

Figure 3-14: Studies in 1991

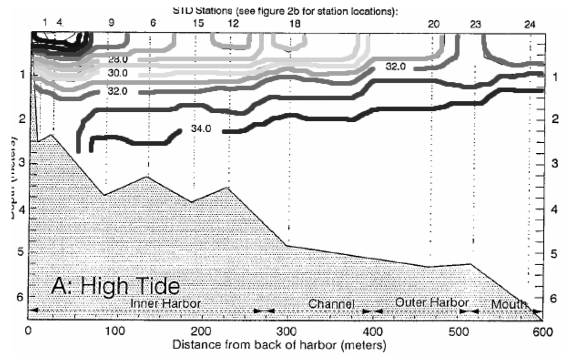

Figure 3-15: Salinity contours at high tide –27 March 1991, from OI Consultants, 1991

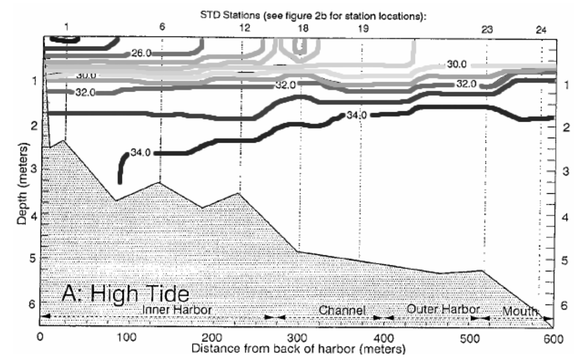

Figure 3-16: Salinity contours at high tide –30 March 1991, from OI Consultants, 1991.

A more recent report presented by University of Hawaii (Glenn, 2006) (see Figure 3-17) also shows that the 29 ppt contour at the surface extends to approximately 500 meters from the back Harbor wall. Finally, recent data collection by Oceanit Laboratories between April 3 and 13, 2006 (Ziemann, 2006) showed a surface salinity of 28.9 ppt at the Harbor entrance, approximately at 500 meters from the back Harbor wall.

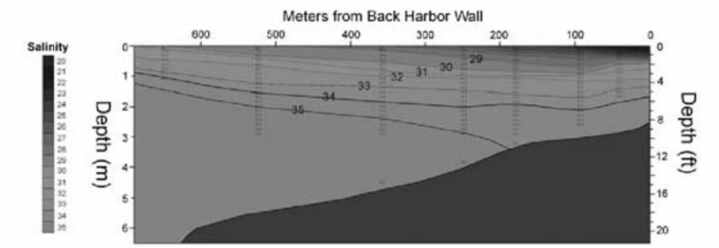

Figure 3-17 : Salinity distribution in February 2006 from University of Hawaii, C. Glenn, November 2006

The consistency of available historical and recent measurements indicate a very stable salinity distribution in the harbor which is probably associated more to the location of the harbor in relation to the density gradients in the groundwater system than to the head differences in the aquifer.

Flushing Time

After the harbor expansion, OI Consultants subcontracted Noda and Associates, Inc. to perform a dye study in order to assess the flushing time of the Harbor. This study was conducted over a 4 day period in March, 1991. Figure 3-14 shows in blue the period when the dye study in the Harbor was carried out (OI Consultants, 1991) together with the water elevation in the Harbor. Rhodameine WT dye in a 20% aqueous solution (about 5 gallons) was injected throughout the Harbor during a five hour period (flooding tide) ending at 13:00 on March 14, 1991. The deployment of the dye was designed such that the dye would be vertically and spatially uniform throughout the Harbor. Measurements were taken at 8:00 on March 15, 16, 17, and 18 in order to assess the concentration throughout the Harbor. The method, described in one of the following sections, was used to determine the residence time at five stations throughout the Harbor.

The analysis was first applied to tidal-only flow exchange with the ocean waters (OI Consultants 1991). The tidal flushing time was computed to be approximately 3.2 days. Measured results from the five stations within the Harbor show much shorter residence times, with stations in the inner part of the Harbor having average residence times of 0.4 days. It was also shown that the residence time at all stations was fairly depth independent indicating that the mixing of the tracer dye and "fresh" water was fairly consistent throughout the Harbor. The representative flushing time for the entire Harbor was the average of all five stations and was 0.42 days, which is 7.6 times faster than the tidal flushing time.

OI Consultants (1991) also noted that the tidal prism is about 16.5 million gallons per day (mgd) and that using the groundwater intrusion calculated by Bienfang (1980) of 1.5 to 2 mgd represents only about 9% to 12% of the flushing volume. This is counterintuitive to the results presented, and indicates that the 1.5 to 2 mgd of groundwater intrusion refers to fresh groundwater and not the total volume of brackish groundwater that enters the Harbor, which could be a significantly larger amount. Gallagher (1980) reported intrusion rates within the Harbor of 70 m^3/min or 27 mgd of brackish groundwater, which is equivalent to 9.5 mgd of pure fresh water. Gallagher (1980) found using a numerical model that the residence time of the Harbor was on the order of 12-13 hours or 0.5-0.54 days.

<u>Calibration data</u>

Based on the available information presented in the previous section, brackish groundwater inflow and the dispersion coefficient in the numerical model were calibrated to meet the following observations:

- Most of the data indicates that the 29 ppt contour at the surface extends to a distance between 400-500 m from the Harbor back wall.
- The depth of the 33 ppt contour is very stable in most of the data sets. Gallagher (1980) used this contour to define an arbitrary boundary between the top and bottom layers inside the Harbor.
- Flushing time should vary between the values reported by OI Consultants (1991), 0.42 days or 10 hours, and those reported by Gallagher (1980), 0.5-0.54 days or 12-13 hours.
- Flushing time is homogeneous with depth as reported by OI Consultants (1991).

<u>*Brackish Groundwater Inflow and Dispersion Coefficient Calibration*</u>

The selected calibration period coincides with the time when OI Consultants (1991) performed the dye study. For each combination of brackish groundwater discharge and dispersion coefficients, the transport of a conservative tracer was carried out using a coupled hydrodynamic and water quality model. The model was seeded with a conservative tracer up to the mouth of the harbor with an initial concentration of 1 g/m^3 at each vertical layer. Outside of the harbor, the concentration was set with an initial value of 0 g/m^3. Conservative tracer model simulations were started at the point of last release of the Rhodameine dye at 13:00 March 14, 1991.

To compare model results to the analysis presented in the study conducted by OI Consultants, Inc., the computation of a flushing time constant, *T*, was used to represent the residence time in the harbor. The same method of computing the residence time used by OI Consultants (1991) was applied in this study. The method is summarized in the following paragraphs.

The concentration of a constituent within an enclosed body of water like a harbor which is dominated by tidal effects can be described by

$$C = C_0 e^{-t/T}$$

Where C_0 is the initial concentration and C is the concentration of the constituent at time t. T is considered to be the flushing time constant or the residence time of the particle in units of time. This approach is often referred to as the "e-folding" approach. The residence time, T, can be considered to be the time required for reduction of a conservative tracer concentration to $1/e$ or

36.8% of its initial value, or a reduction of 63.2%. Mathematically, assuming an exponential distribution of times for individual water particles to reach the ocean, when the concentration of particles reaches 1/e, it represents the average time of all particles to reach the ocean.

If the natural logarithm of the above equation is written as

$$\ln(C) = \ln(C_0) - t/T$$

then it is seen that the natural logarithm of the concentration of a tracer is a linear function of the time with a slope of -1/*T*. In this way, the residence time can be estimated without knowing the initial concentration.

Several combinations of brackish groundwater discharge and dispersion coefficients were simulated. These simulations used a combination of values of brackish groundwater discharge between 8 and 55 mgd and a dispersion coefficient between 0.1 and 1.0 m^2/s. The salinity concentration of the brackish groundwater discharge was selected to be 22 ppt and the temperature 20 ºC, which is in the order of the values observed near the back wall of the existing Harbor.

The following conclusions were obtained from the analysis of the model results

- Groundwater discharge controls the flushing rate of the surface layer. For example, when the inflow rate was kept at a low value such as 4 to 8 mgd, the flushing rate of the surface layer varies between one and more than two days depending of the dispersion coefficient applied.
- The observed vertical salinity distribution in the harbor, with the 29 ppt contour at the surface reaching a distance of 400-500 m from the back wall is only obtained for brackish groundwater discharges larger than 20-25 mgd.
- The field study conducted by OI Consultants (1991) shows flushing time constants within the Harbor to be fairly uniform with depth. In order to achieve the mixing of the conservative tracer throughout the depth layers, a dispersion coefficient closer to the upper limit of the selected range (horizontal dispersion coefficients were varied between 0.1 m^2/s and 1 m^2/s) was needed. It was found that using dispersion coefficients at the upper limit promoted too much mixing, impacting the top layer thickness throughout the Harbor, independently of the flow rate used. For example a flushing time in the order of 12 hours could be obtained for a groundwater discharge as low as 20 mgd but for a dispersion coefficient of 1 m^2/s, which produces excessive vertical mixing creating a top layer (salinity values smaller than 33 ppt) thicker than observed. On the other hand, using dispersion coefficients at the lower limit caused little to no mixing of the conservative tracer in the lower layers over the three day period.
- The best results were obtained for a groundwater discharge of 30 mgd and a dispersion coefficient of 0.7 m^2/s. Flushing time results show low variation with depth (STD about 0.1 days) and a mean flushing time of 0.53 days, which is about 12-13 hours as reported by Gallagher (1980). Increasing the dispersion coefficient to 0.8 m^2/s produced a smaller flushing time but also a thicker than observed top layer. Increasing the groundwater discharge or decreasing the dispersion coefficient moved the 29 ppt contour at the surface too far away from the harbor back wall.

The flushing time results calculated from the model simulated concentration for a groundwater discharge of 30 mgd and 0.7 m^2/s are presented in Table 3-3 at the same five stations reported by OI Consultants (1991) and at the top, middle and bottom of the water column. The full results of the calibration are displayed in Appendix B.

The groundwater discharge is meant only to represent a typical value. While it has been shown (Waimea Water Services, 2006) that the groundwater discharge into Honokohau Harbor varies with tides and seasonal rainfall events, this was not represented by the model.

Table 3-3: Flushing time (days) from the calibrated model 30 mgd and 0.7 m^2/s

	Station 1	Station 2	Station 3	Station 4	Station 5
Top	0.53	0.53	0.53	0.53	0.54
Middle	0.53	0.54	0.54	0.53	0.53
Bottom	0.52	0.52	0.52	0.49	0.52

In addition Figure 3-18 presents the salinity cross section across the harbor obtained from the calibrated model.

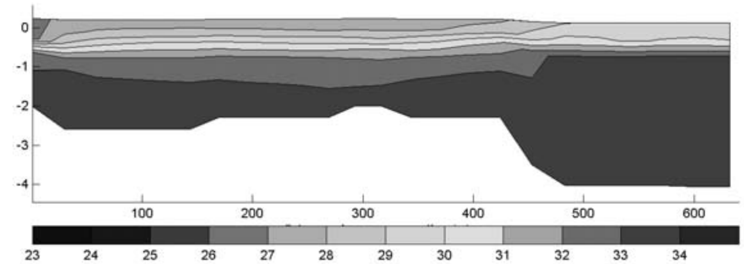

Figure 3-18: Simulated salinity contours (ppt) along Transect EH (Figure 3-12) at high tide –27 March 1991 for 30 mgd and 0.7 m^2/s

3.3 Future Conditions

The existing conditions model presented in the previous section was modified to include the Kona Kai Ola Marina. The future conditions model setup also considers possible brackish groundwater inflows mainly at the eastern side of the new basin. Additional inflows from the exhibit area of the development were included in the model as point sources. The uncertainty of the brackish groundwater inflow into the new Marina prompted a series of tests that examined a range of possible scenarios including the worst expected case. The purpose of this is to enhance the knowledge of the mechanisms controlling the hydrodynamic conditions of the new two-basin system, as well as to provide a range of possible conditions of the system.

The future conditions model was implemented following the same principles used for the existing conditions model described in the previous section. Offshore boundary conditions and bathymetry were kept the same. Conditions in the existing Harbor, including the brackish groundwater inflow were also kept the same. The new marina required additional parameters which are described in detail in the following sections.

3.3.1 Model Grid

The model grid developed in the previous section to simulate the existing conditions at Honokohau Harbor was extended to include the proposed area for the Kona Kai Ola Marina. Figure 3-19 shows the extent of the grid expansion. The offshore sections of the grid remained entirely unchanged. The grid extension does not encompass the area designated for the exhibit areas. These areas are included in the model as point sources of inflow.

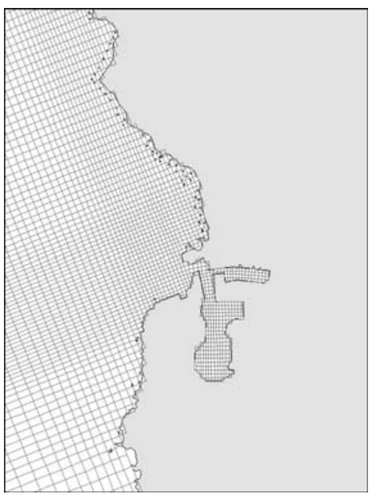

Figure 3-19: Model Grid Including the Kona Kai Ola Marina

3.3.2 Model Bathymetry

The same offshore and existing Harbor bathymetry used in the existing conditions model was also used in the future conditions model. The Kona Kai Ola Marina bathymetry and layout was built following the design plans included in the EIS. Figure 3-20 presents the future conditions model bathymetry.

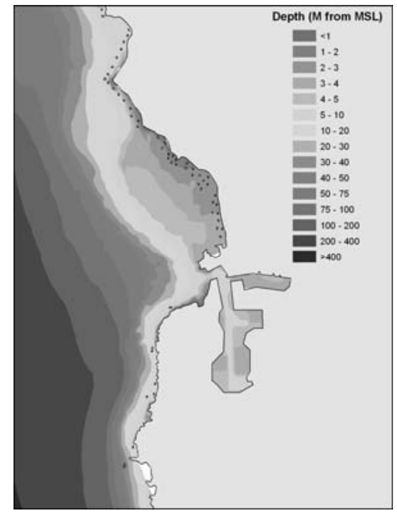

Figure 3-20: Model bathymetry including the Kona Kai Ola Marina

3.3.3 Model Boundaries and Additional Inflow into Kona Kai Ola Marina

Conditions at the offshore boundaries are the same described and applied in the existing conditions model. It is assumed that brackish groundwater discharge into the existing Harbor will remain the same after the construction of the new Marina. Additional inflows into the new Marina consist of discharges generated by the exhibit area and brackish groundwater inflow through the porous volcanic ground, mainly through the east wall of the new Marina. The exact value of this additional inflow is not known. In order to compensate for the unknown inflow, the model solution was bracketed between no flow conditions and twice the observed value under existing conditions (in addition to the present inflow). No flow conditions were analyzed in order to look at a control scenario which is suspected to be the worst case scenario in terms of flushing. A value of 30 mgd would represent persistence of the current conditions, since that it the value present in the existing marina and therefore it is considered a good starting point for analysis. Values of 15 mgd and 60 mgd represent a factor of two increase and decrease of inflow from the starting point. The simulated conditions are summarized in Table 3-4. A complete groundwater study would be needed in order to estimate with confidence the amount of brackish groundwater flow that would enter the new Marina. Other possible inflows into the new Marina such as the one associated with the SWAC air-conditioning system have not been considered in this study.

Table 3-4: Summary of tests used for description of future hydrodynamic conditions at the new Marina

Case 1	Brackish discharge = 0 mgd Exhibit discharge = 0 mgd
Case 2	Brackish discharge = 15 mgd Exhibit discharge = 0 mgd
Case 3	Brackish discharge = 30 mgd Exhibit discharge = 0 mgd
Case 4	Brackish discharge = 60 mgd Exhibit discharge = 0 mgd
Case 5	Brackish discharge = 0 mgd Exhibit discharge = 75 mgd
Case 6	Brackish discharge = 15 mgd Exhibit discharge = 75 mgd
Case 7	Brackish discharge = 30 mgd Exhibit discharge = 75 mgd
Case 8	Brackish discharge = 60 mgd Exhibit discharge = 75 mgd

Part of the flow that enters the new Marina from the exhibition area flows through three waterfalls and the rest is piped into the new Marina. This water is originally pumped from offshore at a depth of approximately 100 m with a flow rate of 75 mgd. The intake depth was selected to minimize the nutrient loads of the water (pers. comm. ClowardH2O, 2007). The water is then pumped to the exhibition area. The water is at an oceanic salinity (34 ppt) and has a temperature when withdrawn of approximately 3 ºC less than the surface water. Assuming that the pumping and subsequent movement through the exhibition area will serve to increase the temperature approximately 1 degree, it is assumed that the inflows to the new harbor are approximately at a temperature of 23 ºC (all assumptions and calculations with relation to the exhibit water were obtained from pers. comm. ClowardH2O, 2007). The water is expected to have an approximate 4 hour residence time within the exhibition area (pers. comm. ClowardH2O, 2007)

Brackish groundwater flowing into the new Marina is assumed to enter the basin only through the eastern side. The brackish groundwater inflow (15, 30, or 60 mgd) is equally distributed along all the grid points on that the eastern side of the Marina. In spite of the uncertainty associated with this assumption, mainly because some areas of the Harbor extension cut into the groundwater table further inland than others, it is considered to be a reasonable range of values to represent the system.

3.3.4 Flushing Under Future Conditions

The new Marina to be developed as part of the Kona Kai Ola Master Plan is much larger in volume than the existing Harbor. Table 3-5 shows the approximate volume of the existing marina and the new proposed one. Note that the volume of the new Marina does not include the

exhibit area, just the main basin. The Kona Kai Ola Marina is about 5 times larger (by volume) than the existing Harbor, and therefore, the combined system will have a volume six times the existing volume, while the connection to the ocean of the combined system will be maintained as today. The increase in flow into the system with the construction of the new Marina affects the Harbor mouth, primarily due to the increased new outflow from the new Marina. Therefore, the quantity of water that has to leave through the mouth of the combined system will increase from the existing conditions value as the inflows into the new Marina increase.

Table 3-5: Water volumes, from MSL, of existing and proposed marinas

Existing	3,936 m^3
Proposed	19,142 m^3

Flushing time is an important indicator of water quality, as it describes in this particular study the time that certain substance will remain in the harbor. The faster particles, pollutants, or algae flush out of the system, the less build-up there will be within the harbor, and the less chance there will be of major water quality problems like eutrophication and as stated by Ferreira *et al*. (2005), flushing is the primary means of maintaining water quality and biodiversity within a harbor. In previous sections, the flushing time under existing conditions was discussed. This section attempts to quantify the flushing time under a range of potential future conditions after the development of the Kona Kai Ola Marina. Eight cases were analyzed with four brackish groundwater inflow rates. While the exhibit area is a definite feature of the Conceptual Master Plan, its influence on the flushing time of the combined harbor system was assessed independently.

The flushing time was computed using the method outlined for existing conditions. The five stations described under existing conditions were also used in this analysis for the existing Harbor. These points coincide with those from the 1991 OI Consultants dye study. In addition, seven points were selected within the proposed new Marina. Each section of the Harbor was analyzed separately in order to determine the effects of the new Marina on each area. It is important to note however, that the entire system is treated as one system. Water flowing between the existing and new marinas is not considered to be flushed out to the ocean. Only "clean" water (ocean and brackish water inflows) from outside the system can flush the entire system. This is an important factor in the flushing time calculation of the entire system because as it is shown in later sections that there is a significant internal circulation between the two marinas. Rather than show the flushing time at each point, an average value for the entire Harbor section was computed. These average values are displayed in Table 3-6 and Table 3-7 for the existing and new marinas respectively.

Under existing conditions, the average flushing time of the existing Harbor was computed to be 0.53 days or 12.7 hours. After the addition of the new Marina to the system, the new flushing times for the existing Harbor under the highest brackish groundwater flow conditions simulated (60 mgd) increased to 19 hours. In general, for all the simulated cases, the area with the highest flushing times is the one at the back end of the new Marina. These flushing times were higher than 2 days in the case of no brackish groundwater discharge.

Table 3-6: Flushing times for the existing Harbor in days

Case	No Exhibit Flow	Exhibit Flow Included
Discharge 0 mgd	1.38	1.49
Discharge 15 mgd	1.11	1.10
Discharge 30 mgd	0.98	0.94
Discharge 60 mgd	0.86	0.83

Table 3-7: Flushing times for the Kona Kai Ola Marina in days

Case	No Exhibit Flow	Exhibit Flow Included
Discharge 0 mgd	2.39	1.72
Discharge 15 mgd	1.76	1.32
Discharge 30 mgd	1.44	1.09
Discharge 60 mgd	0.97	0.91

The simulated cases were designed to provide a range of solutions that span the possible post-expansion conditions. Since the flushing time decreases as the brackish groundwater inflow into the new Marina increases, the worst case scenario will be the one where the brackish groundwater inflow to the new marina is 0 mgd. The different brackish groundwater inflows simulated can be used to define an array of possible solutions, since the exact volume of groundwater is not known. A complete groundwater investigation would be needed to asses the quantity of brackish water entering the Harbor, although this value will not be known with certainty until the project construction is completed. However, from this analysis, it is seen that after construction of the new Marina, even with relatively high brackish groundwater inflow conditions (60 mgd in the new Marina and 30 mgd in the existing Harbor), it is not expected that the flushing time for the existing Harbor will decrease or even remain the same as under the current conditions. The results demonstrate that the flushing time is not only dependent on the volume of water entering the harbor system but also on the density driven circulation patterns associated with that addition. Given the new Marina basin is approximately five times the volume of the existing Harbor, even using the most optimistic scenario (brackish discharge of 60 mgd and a 75 mgd exhibit outflow, with a total = 5 times the 30 mgd used as inflow to the existing Harbor), the flushing time of the new Marina is 0.97 days which is significantly higher than the 0.53 days experienced under the current conditions.

It is also evident that while the 75 mgd of saline inflow coming from the exhibits does have a positive effect on the flushing time of the new Marina, the results indicate that this saline inflow does not have a significant effect on the existing Harbor's flushing. It is also apparent that smaller quantities of brackish water have more of an effect on the new Marina than does the saline inflow due to the density driven currents that result.

3.3.5 Circulation under Future Conditions

Model results indicate that circulation within the existing Harbor will be modified by the addition of the new Marina. While there is still a well defined two-layer system with a seaward-moving surface layer of brackish water. This surface layer is diverted into the more saline new Marina.

Currents within the new Marina develop into a complicated system. Figure 3-21 through Figure 3-24 show a cross section (Transect NM, Figure 3-12) along the center of the new Marina from south to north (the back wall of the new Marina is located at the left side of the figures) with contours of the velocity in m/s. At lower brackish groundwater inflow rates, the vertical distribution of salinity and velocities in the new Marina consists of three distinct layers (Figure 3-21, Figure 3-23). The top layer is flowing into the harbor with low density water from the existing Harbor. The bottom layer is high salinity oceanic water flowing in from the mouth. The middle layer is flowing out of the new Marina as the higher density oceanic water pushes it up and out of the existing Harbor and new Marina system.

With higher brackish groundwater inflows, the system approaches a two layer system (Figure 3-22 and Figure 3-24) closer to the one observed in the existing Harbor. The surface inflow from the existing Harbor is reduced and does not penetrate into the new Marina as much as observed under lower brackish groundwater inflow conditions.

The impact of the 75 mgd inflow from the exhibits into the new Marina could be estimated by comparing the simulation results without the inflow (Figure 3-21 and Figure 3-22) and those with the inflow (Figure 3-23 and Figure 3-24). Simulation results show that the density driven circulation is reduced when the exhibit inflow is included, since the water in the new Marina becomes more saline.

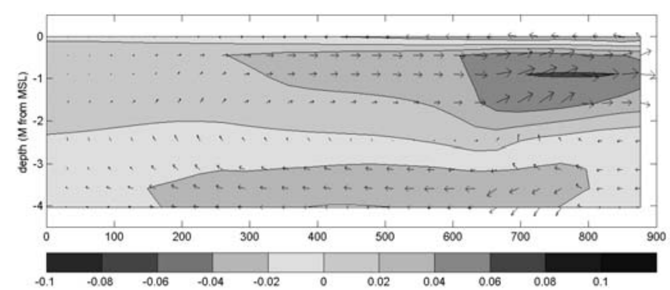

Figure 3-21: Currents at peak flood (m/s) along Transect NM (Brackish discharge of 0 mgd)

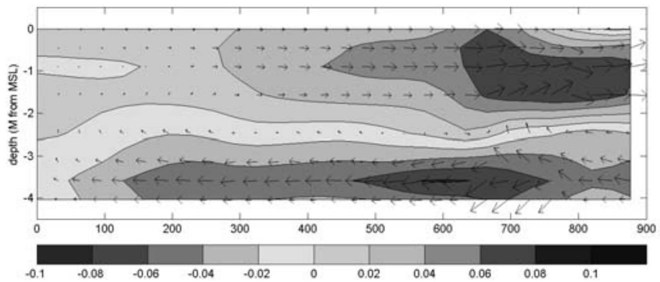

Figure 3-22: Currents at peak flood (m/s) along Transect NM (Brackish discharge of 60 mgd)

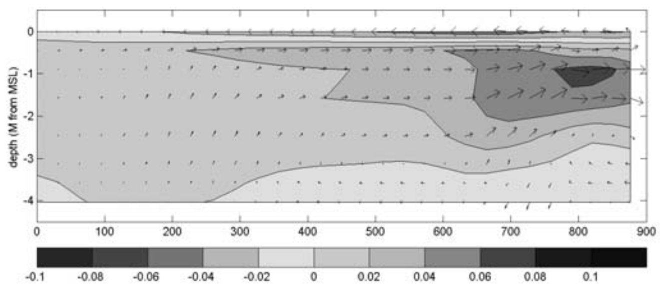

Figure 3-23: Currents at peak flood (m/s) along Transect NM (Brackish discharge of 0 mgd and exhibit discharge of 75 mgd)

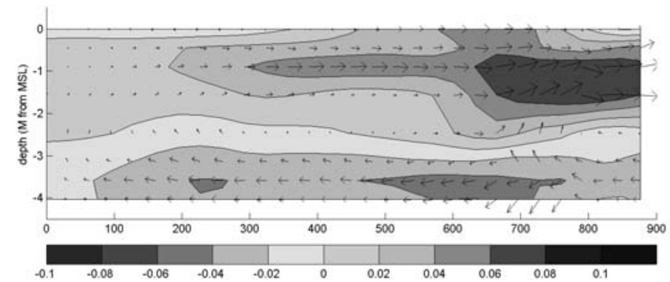

Figure 3-24: Currents at peak flood (m/s) along Transect NM (Brackish discharge of 60 mgd and exhibit discharge of 75 mgd)

Currents at the mouth of the harbor system (harbor mouth, Figure 3-12) are also affected by the increase in flow from the new Marina. Figure 3-25 and Figure 3-26 show how the velocity profile varies at the harbor mouth for flood and ebb tides under different brackish groundwater inflow conditions at the new Marina and also with the additional inflow from the exhibits. The most significant change with respect to existing conditions is observed during ebb flow, when, for the cases with low brackish groundwater inflow into the new Marina, the deep dense water layer moving into the Harbor is canceled. Under these conditions, the water is moving seaward at all depths in the water column, with a significant increase of the surface currents with respect to existing conditions. This effect during ebb flow is more pronounced when the inflow from the exhibit is included in the simulations (see Figure 3-26). During flood flow, the two-layer system observed under existing conditions is maintained, though the magnitude of the velocity at both layers increases.

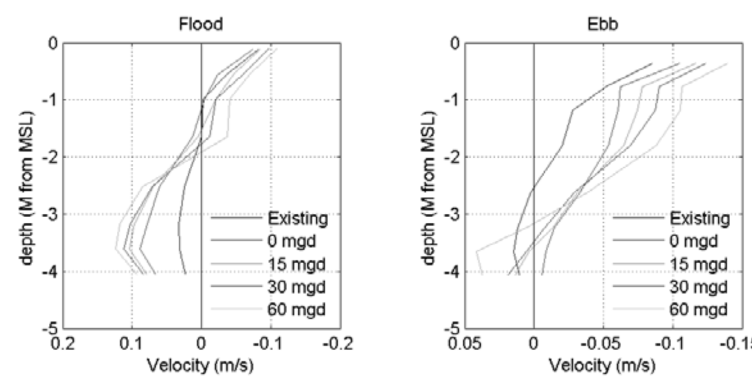

Figure 3-25: Velocity profiles at harbor mouth for 0 mgd exhibit flow

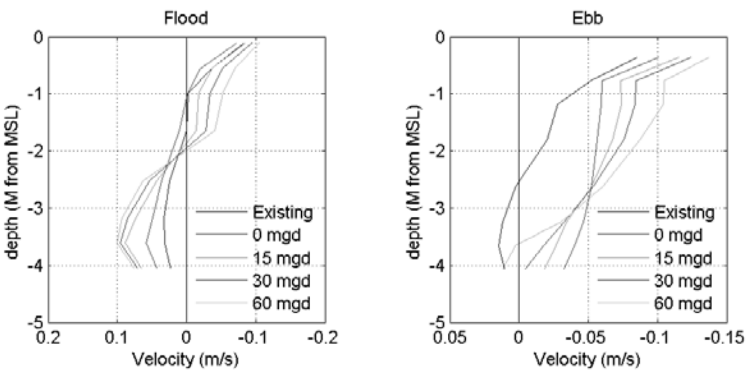

Figure 3-26: Velocity profiles at the harbor mouth for 75 mgd exhibit flow

3.3.6 Salinity

Salinity distribution in the new Marina is controlled by several different sources: the saline ocean water from the exhibits (75 mgd), brackish groundwater inflows, and the exchange between the existing Harbor (surface brackish water) and the ocean (bottom saline water). The vertical salinity distribution along a central cross-section of the new Marina for the simulations with low brackish groundwater inflow shows a very small variability in salinity with a small area of brackish water at the surface near the harbor entrance. Figure 3-27 and Figure 3-29 show the salinity contours for the cases with 0 mgd brackish groundwater inflow. Results from these simulations show high salinity concentrations at the far end of the Harbor in the range of 31 to 33 ppt. Overall, in these cases, the salinity within the new Marina remains higher than that in the existing Harbor. Figure 3-28 and Figure 3-30 show the salinity contours along transect NM (Figure 3-12) for the cases with 60 mgd brackish groundwater inflow. These cases show much more brackish water in the surface layers with saline water being confined to the bottom layers. It is observed in Figure 3-29 and Figure 3-30 that including the 75 mgd inflow of 34 ppt water from the exhibits reduces the stratification and increases the salinity concentration in the new Marina.

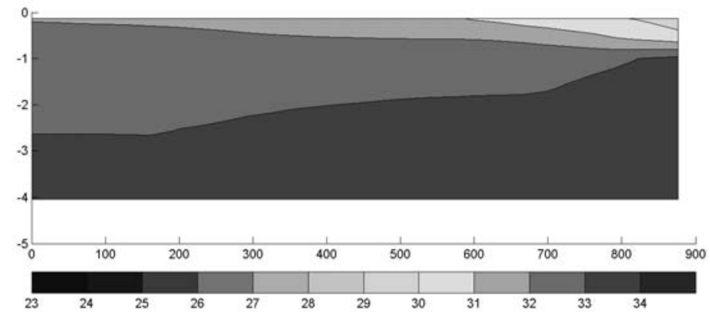

Figure 3-27: Salinity contours at flood tide (ppt) along Transect NM (Brackish discharge of 0 mgd)

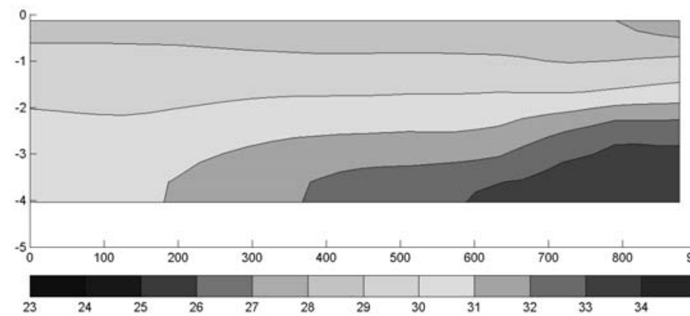

Figure 3-28: Salinity contours at flood tide (ppt) along Transect NM (Brackish discharge of 60 mgd)

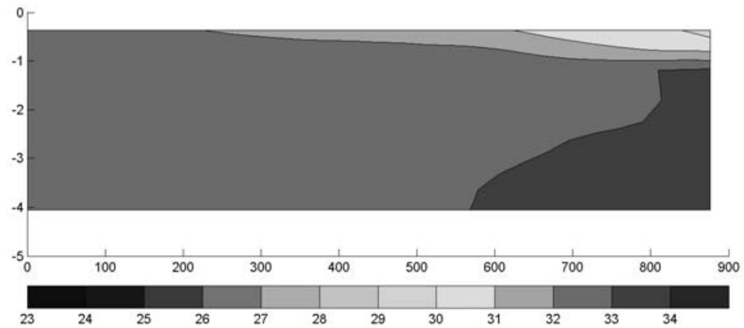

Figure 3-29: Salinity contours at flood tide (ppt) a along Transect NM (Brackish discharge of 0 mgd and exhibit discharge of 75 mgd)

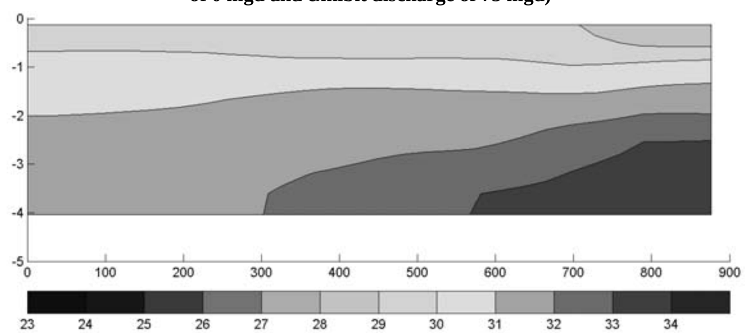

Figure 3-30: Salinity contours at flood tide (ppt) along Transect NM (Brackish discharge of 60 mgd and exhibit discharge of 75 mgd)

Salinity patterns within the existing Harbor are also altered under future conditions due to the change in circulation. Circulation between the two marinas impacted the existing Harbor decreasing its water exchange with the ocean significantly. This was already evident after examining the significant change in flushing times presented in Section 3.3.4. Figure 3-31 and Figure 3-33 show the net salinity changes along Transect EH (Figure 3-12) with 0 mgd of brackish groundwater inflow into the new Marina. In this case changes are small and limited to the region where the two marinas connect. In this region, the salinity in the surface layer slightly increases because the low salinity water in the top layer flows into the new Marina instead of towards the ocean. Figure 3-32 and Figure 3-34 show the net tidally averaged salinity changes along Transect EH associated with the simulated conditions brackish groundwater inflow of 60 mgd into the new Marina. In these cases, the salinity concentration throughout the whole existing harbor is significantly reduced. This is probably a consequence of the new circulation

patterns of the combined system, where the brackish layer flowing out of the new Marina flows into the existing Harbor under the existing fresher water of the surface, blocking denser ocean water from moving into the bottom layer of the existing Harbor. As a consequence, dense ocean water flows through the bottom layer into the new Marina under the exiting brackish water. The addition of the 75 mgd of saline water coming from the exhibits reduces this effect since the flow out of the new Marina is then slightly more saline. Therefore the reduction in salinity in the existing Harbor is less pronounced.

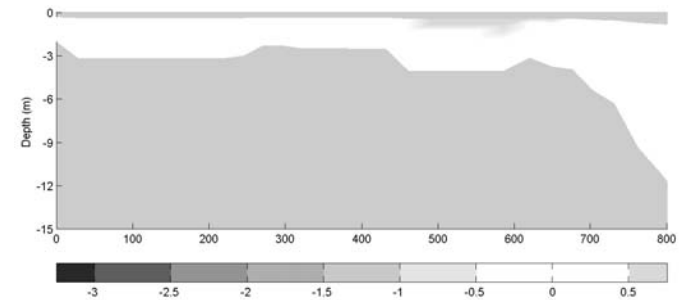

Figure 3-31: Salinity change (ppt) along Transect EH (Brackish discharge of 0 mgd)

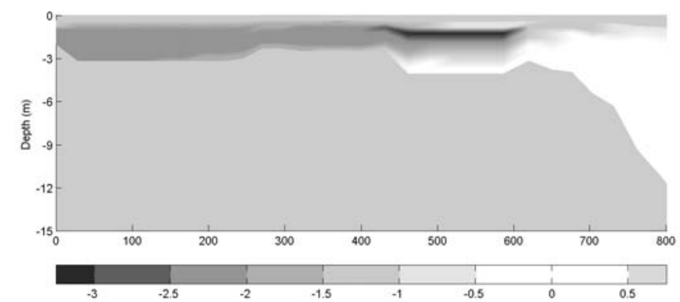

Figure 3-32: Salinity change (ppt) along Transect EH (Brackish discharge of 60 mgd)

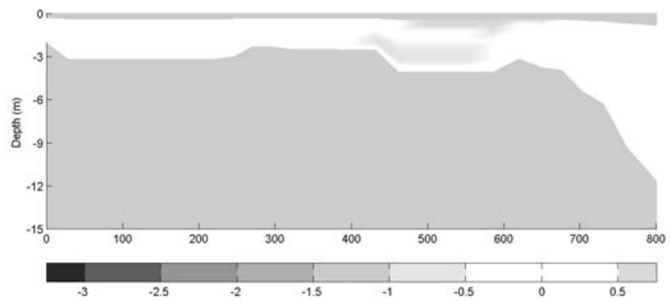

Figure 3-33: Salinity change (ppt) along Transect EH (Brackish discharge of 0 mgd and exhibit discharge of 75 mgd)

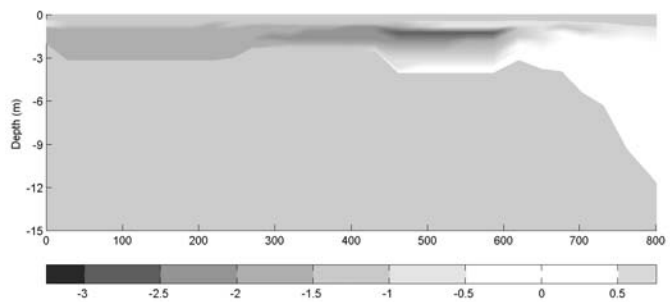

Figure 3-34: Salinity change (ppt) along Transect EH (Brackish discharge of 60 mgd and exhibit discharge of 75 mgd)

In order to further investigate the effects of the water circulating through the two marinas, the salinity profiles at the intersection of the new Marina and the existing Harbor (intersection, Figure 3-12) are shown in Figure 3-35. It is seen that as the quantity of brackish groundwater in the system increases, the well defined two-layer system present under existing conditions changes into a vertical distribution of salinity, which is almost linear over depth. This is observed for both cases with and without the 75 mgd of saline inflow from the exhibits, though the salinity through the middle to bottom layers is slightly more saline when the inflow from the exhibit is included.

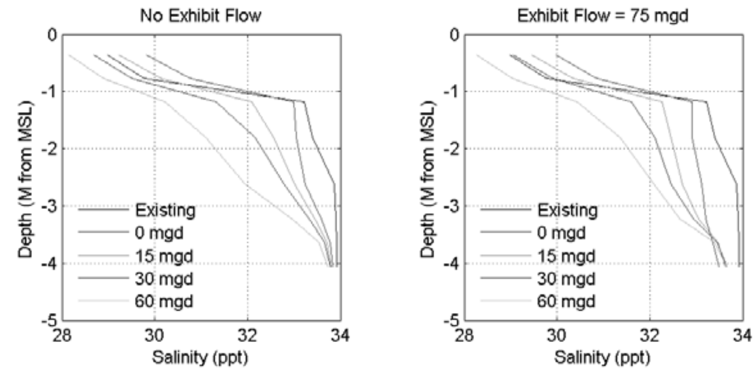

Figure 3-35: Salinity profiles at the intersection of existing and extended harbor

4. WATER QUALITY MODEL

The water quality module, Delft3D WAQ, simulates two-dimensional (2D, depth averaged) or three-dimensional (3D) transport and physical, biological and biochemical phenomena for a variety of model substances. The physical transport is governed by the advection-diffusion-reaction equation which is discretized for each computational cell. The physical transport is dependent on physical position, as is described in the hydrodynamic module. In addition to physical transport, Delft3D WAQ implements the biological and chemical reactions that affect each modeled constituent. This represents the complexity of interactions between substances and processes, which are independent of spatial position.

Delft3D WAQ is based on a flexible interface that allows the user to define the processes and components that are included within the model. The equations governing the processes for each substance are coupled together, giving a fully integrated water quality model. Given this, the computational time for the model increases with both the number of modeled substances and the complexity of the interactions. Process coefficients are defined within the model and are easily changed for calibration and sensitivity purposes. Initial and boundary conditions for the modeled substances can be defined within the model.

The model developed for Honokohau Harbor is necessarily site-specific. The substances and processes chosen for modeling are the ones most important to the overall water quality of the Harbor. The main goal of the study is to analyze the potential changes in water quality associated to the addition of the Kona Kai Ola Development including the new Marina and water exhibits. Therefore, it is important to develop a model to simulate the existing water quality conditions that can easily be extended to include the new developments. Of particular importance within the harbor are the aerobic conditions that are consistently observed in the existing Harbor. Modeling efforts presented here include the simulation of the existing conditions, and they also attempt to quantify the predicted changes to occur after the construction of the new development.

The kinetics that were implemented in the Delft3D-WAQ module were designed to predict the typical phytoplankton production in addition to this population's relation to the nutrient supply and the overall effect on the supply of oxygen within the water column. The model was designed to incorporate daily variation and seasonal variation; however, the data available did not provide seasonal or even daily variation. So the model was designed to predict an average value that was in line with the available data. This value is considered to be typical and this typical value is sufficient for the purposes of predicting the effects of the new development.

The substances used to quantify these conditions within the harbor are shown in Table 4-1. These values were chosen based on available data for input conditions and calibration (OI Consultants, 1991 and Ziemann, 2006). The interactions of the variables are described in detail in the following sections.

Table 4-1: Modeled substances

Phytoplankton	Diatom chlorophyll a
	Non-diatoms (green algae) chlorophyll a
Zooplankton	Herbivorous zooplankton
Nitrogen	Nitrate-nitrogen
	Ammonium-nitrogen
Phosphorous	Reactive phosphorous (ortho-Phosphate)
Silica	Reactive silicate
Oxygen	Dissolved oxygen

4.1 Model Grid and Hydrodynamics

The physical transport mechanisms necessary to drive the advection-diffusion equation are determined from the hydrodynamic model using Delft3D-FLOW. Hourly hydrodynamic updates were passed to the water quality model. The results of the hydrodynamic conditions were discussed and presented in the previous sections. The hydrodynamic results computed by Delft3D-FLOW were used to drive the water quality model. These hydrodynamics were coupled such that the Delft3D-WAQ module could easily derive the flow field and other parameters such as salinity and water temperature at each hydrodynamic time step. The model grid used for the hydrodynamic computations was also used for the WAQ model. The three-dimensional model grid was described in the hydrodynamic modeling section of the report. The vertical model discretization in 8 vertical layers allows for the simulation of the vertical variation in water quality parameters. Due to the complexity of the flow fields generated in Honokohau Harbor, this three-dimensional distribution is essential to understanding the water quality issues within the Harbor and surrounding areas. Horizontal dispersion was calibrated within the hydrodynamic model, and vertical eddy diffusion coefficients in the water quality model were computed by the hydrodynamic model using a k-ε turbulence closure scheme.

4.2 Temperature and Salinity

The biological elements (phytoplankton) present in the Harbor are strongly influenced by the temperature and salinity variation. The temperature dependency of the reaction rates has a uniform exponential equation.

$$k = k^{20} x k_T^{(T-20)}$$

k is the rate constant at some arbitrary temperature, T. The reference temperature for Delft3D-WAQ is considered to be 20 degrees Celsius, and k^{20} is the rate constant at this temperature. k_T is the temperature coefficient, which usually ranges between 1.01 and 1.10.

Temperature was determined within the Delft3D-FLOW hydrodynamic model. It included a heat-flux model taking into account air temperature, a typical wind speed and percent cloud cover. Evaporation and conduction were also included in the computation. Solar radiation was implemented within the Delft3D-WAQ model and controlled the quantity of light penetrating the water column.

Similarly to temperature, salinity variation has an effect on the biological and chemical reactions occurring within the Harbor. Salinity is also extracted from the hydrodynamic computation and is used to force the water quality model. Both salinity and temperature effects on the flow field are neglected within the water quality module as they were calculated within the hydrodynamic model. In fact, there is no feedback from the water quality module to the hydrodynamic module, and therefore none of the substances within the water quality module can affect or modify the flow field generated by Delft3D-FLOW.

4.3 Dissolved Oxygen

Dissolved oxygen (DO) is often taken as a representation of the health of a water body. Low values of DO indicate that the water is not able to sustain aerobic conditions and that the demand for oxygen exceeds the supply. The sources of DO within the water column come from reaeration at the water surface–air interface and the production of oxygen by phytoplankton during growth. Oxygen is utilized during nitrification, carbon decay, and respiration of both phytoplankton and zooplankton.

If the DO concentration is greater than the saturation concentration (supersaturation) at that temperature and salinity, the water will release oxygen to the atmosphere; however, if the water is undersaturated, then the water will take on oxygen from the atmosphere through reaeration. Stratification within the water column can cause significant water quality problems as the hypolimnion is not in contact with the atmosphere and cannot replenish the oxygen concentration from the atmosphere.

The only chemical reaction utilizing oxygen that is incorporated by Delft3D-WAQ in the Harbor simulations is the reaction converting ammonium to nitrate, which is discussed in Section 4.4. In addition, Deflt3D-WAQ contains the capacity to include collective parameters that indicate oxygen demand, such as Chemical Oxygen Demand (COD), or Biological Oxygen Demand (BOD) in order to encompass other processes and sources of demand that are not explicitly present within the model (WL| Delft, 2004). Available data on the oxygen demands on the system aside from nitrification were not available, and were not included in the model.

Phytoplankton respiration occurs during both day and night; however, primary production only occurs during the daylight hours, when photosynthesis can take place. Therefore, there is generation of oxygen occurs only during the day, while only consumption can occur at night. Due to this, there will be lower DO Oxygen values during the nighttime.

4.4 Nitrification

From a modeling perspective, nitrogen is difficult to model due to its loading pathways. In addition to the varying nitrogen species created from varying degrees of oxidation, loading may result from nitrogen-fixing bacteria and algae utilizing atmospheric N_2 gas directly to satisfy photosynthetic nitrogen requirements (when nitrogen is limited in the water column) or from bacterial conversion of organic nitrogen to NH_4-N at the sediment water interface. Nitrogen losses may occur due to denitrification (anaerobic conversion of organic nitrogen to N_2 gas) in the reducing environment found in the sediment-water interface. Additionally, nitrogen is generally identified with the dissolved water column constituents and cycles easily throughout the water column.

One of the significant sources of oxygen demand within a system is the nitrification of ammonium to nitrate. When a high ammonium loading comes from sewage or fertilizers, the

oxygen demand can be extremely problematic to these water systems. Ammonium in aerobic conditions is oxidized to nitrite by the bacteria Nitrosomonas.

$$NH_4 + 1.5O_2 \rightarrow 2H^+ + H_2O + NO_2^-$$

The nitrite formed is then oxidized to nitrate-nitrogen by the bacteria Nitrobacter.

$$NO_2^- + 0.5O_2 \rightarrow NO_3^-$$

Therefore the total oxygen utilization in the oxidation of ammonium is 4.57 g-oxygen per g-ammonia-nitrogen. In order for this process to commence, the conditions must be aerobic (DO>2.0 mg-O_2/L), o-P must be present, and the environment must be alkaline with a pH between 6.0 and 8.5.

The oxygen consumption due to the nitrification of ammonium is proportional to a nitrification rate (obtained from EPA: Lake Erie Model (1980)) and a function of the DO and ammonium concentration. If the system becomes anaerobic, denitrification takes place, although within Honokohau Harbor, this condition is not applicable.

4.5 Phytoplankton

Phytoplankton are non-motile, plant-like bacteria, which similarly to plants only grow, and thus release oxygen, in the presence of light. If phytoplankton are present in large quantities, they can consume the oxygen within the system through respiration and cause the system to become eutrophic. Phytoplankton growth is limited by the presence of consumers (zooplankton) and the availability of nutrients within the system. In Honokohau Harbor, two types of phytoplankton are considered, diatoms and non-diatoms (green-algae). Only two types were chosen for modeling due to the availability of only Chlorophyll a concentration values, so a sophisticated species specific model is unreasonable given the calibration data. A “typical” ratio of 25 mg-CHLa to 1g-C for phytoplankton (Chapra 1997) was used to convert between carbon and chlorophyll for the purposes of the model inputs. Diatoms and non-diatoms are differentiated only by the diatom’s silica requirement. The cell wall of the diatom is made up of silica and if there is a bloom of diatoms, a depletion of silica within the system would be noticeable. The stoichiometric composition of the diatom and the typical green algae (classical ratios for O:C:N:P (109:41:7.2:1) is similar in proportion neglecting the silica (Chapra, 1997).

Growth, or primary production, occurs during daylight hours and requires that there be enough nutrients present. The typical growth rate of maximum production was obtained from EPA: Lake Erie Model (1980). Nutrient dependency relates the growth rate of the phytoplankton to the external nutrient concentrations. Phosphorous, nitrogen, carbon, and silica (for diatoms) are the potential limiting factors, although in most models, carbon is not assumed to ever limit growth (Chapra, 1997). Delft3D-WAQ utilizes a model for primary production using Monod-type kinetics for the calculation of growth rates. Primary production is proportional to the biomass concentration and the gross primary production (growth) rate. The consumption of inorganic nutrients and production of DO is proportional to the net primary production (WL| Delft, 2004).

In order to determine the limiting nutrient for phytoplankton growth, the N:P ratio is used. The ratio of nitrogen to phosphorous in the biomass of phytoplankton is roughly 7.2 (Chapra, 1997). Therefore, a ratio in the water of less than 7.2 indicates that nitrogen is the limiting factor.

Conversely, higher ratios indicate that phosphorous will limit growth. In the case of Honokohau Harbor, the ratio of N:P in 1991 was approximately 6 which would make the system nitrate-nitrogen-limited. This was also the case pre-expansion (Bienfang, 1980). In 2006, the data presented by Ziemann shows the system o-P to be lower in concentration at all depths than in earlier studies (Bienfang, 1980 and OI Consultants, 1991) and the system appears to have become phosphorous-limited. This might imply that phosphorous loading has changed, since the groundwater ratios of NO_3-N to o-P remain fairly constant. The limiting factor has a significant impact on phytoplankton growth and is important to consider. Due to the apparent shift in limiting nutrients, the difficulty in calibrating the model between the two datasets is evident in later sections of this report.

For the purposes of this model, biological and chemical interactions with the sediment layer were neglected; however, the settling of phytoplankton is important and typical settling velocities were obtained from Burns and Rosa (1980) and from EPA: Lake Ontario Model (1975). The settling of phytoplankton only occurs when the bottom shear stress, computed in the hydrodynamic model, drops below a critical value. Dead phytoplankton are converted to inorganic nutrients, and the mortality is controlled by the biomass concentration and a mortality constant, which was obtained from EPA: Rates, Constants and Kinetics (1985).

4.5.1 Primary Consumption

The presence of primary consumers such as zooplankton can significantly impact the phytoplankton population in a system. This model accounts for the first level of consumers, the herbivorous zooplankton, however carnivorous zooplankton and higher levels of consumers were not included within the model. While the respiration of zooplankton has an effect on the DO content within the water column, this effect is ignored in Delft3D-WAQ (WL|Delft, 2004). The stoichiometry of the primary consumers is defined, and generally is considered to be related to the composition of their food supply. The uptake rate of phytoplankton biomass for food, respiration and mortality of biomass, and excretion of nutrients are included in the model (values obtained from EPA: Rates, Constants, and Kinetics, 1985). Concentrations of zooplankton were reported in OI Consultants (1991) and Bienfang (1982).

4.6 Model Conditions

The model was set up using Delft3D-WAQ which is a three-dimensional numerical model with the capacity for multiple substances and varying processes. The processes and substances included in the model set up were described at length in the previous section. The hydrodynamic conditions used to drive the water quality model were discussed at length in Section 3. The water quality model was developed to fit the processes and specifics of Honokohau Harbor under existing conditions. It was calibrated to data collected in 1991 (OI Consultants, 1991) and verified using data collected in 2006 (Ziemann, 2006). The proposed expansion of the Harbor was analyzed using the calibrated and validated numerical model to describe the changes that are expected to occur with the extension of the harbor and the additional loads associated with this new Marina.

The grid and bathymetry used for the water quality module were the same as those presented in the hydrodynamic section. Seasonal variability in the water quality model was not considered since such information was not available for calibration and therefore the model was

implemented under "typical conditions." A spring-neap tidal cycle was simulated; however, the model was calibrated to an average value and not to daily or tidal variability. In addition, neither variations in brackish water inflows nor variations in nutrient loadings were considered in the model. Daily variation was considered to the extent that phytoplankton do not grow without the presence of sunlight.

In order to drive the water quality model, conditions for all modeled constituents had to be specified at the initial time in addition to specifications at each boundary and inflow. The oceanic conditions shown in Table 4-4 were applied to every cell within the model as initial conditions. These conditions were also used at the offshore boundaries. The offshore boundaries were sufficiently far enough away from the site that the boundary conditions at the boundary have no immediate direct effect on the site conditions.

Initial and boundary conditions for the model were taken from site specific data sources when possible and supplemented with appropriate literature values. All of the initial and offshore boundary conditions were taken from the offshore transect data collected by Ziemann (2006). The transect data was taken over three days and at two depths: near the surface and near the bottom. The furthest point along all transects was 500 m from the shoreline (Table 4-2). This point was selected to represent the offshore conditions for the numerical model (Table 4-4)

Table 4-2: Offshore statistics (Ziemann, 2006 – 500 m from shore)

	Dissolved Oxygen (mg/L)	Silica (µg-Si/L)	Ortho-Phosphate-phosphorous (µg-P/L)	Nitrate-nitrogen (µg-N/L)	Ammonia-nitrogen (µg-N/L)	Chlorophyll a (µg/)
Mean	7.13	312.87	2.967	21.13	1.430	0.210
Standard Error	0.05	65.12	0.162	4.34	0.197	0.030
Median	7.14	172.50	3.000	14.00	1.100	0.145
Mode	7.05	173.00	3.000	5.00	0.500	0.130
Standard Deviation	0.29	356.70	0.890	23.75	1.077	0.166
Minimum	6.54	68.00	2.000	3.00	0.500	0.090
Maximum	7.94	1869.00	6.000	120.00	4.400	0.700
Count	30.00	30.00	30.00	30.00	30.00	30.00
Confidence Level (95.0%)	0.11	133.20	0.332	8.87	0.402	0.062

The selected offshore conditions were applied as the constant offshore boundary and also as initial conditions for the model. In order to convert the Chlorophyll a concentration to concentrations of diatoms and algae respectively, the ratio of 1:20 for diatoms to algae was used, which was consistent with data obtained by Brix *et al.* (2006) for their study in central Pacific waters. In addition, the typical value of 25 µg-CHLa/L to 1 mg-C/L (Chapra, 1997) was used to convert the measured data to model inputs and vice versa.

Data was also needed to provide the conditions for the brackish water inflows entering the system at the back of the Harbor. Several studies were conducted with respect to groundwater conditions in Honokohau Harbor. Waimea Water Services, Inc. (2006) published a report on the state of the groundwater and brackish water flowing into Honokohau Harbor. Cited in this report is the water chemistry from the project area that was collected in the 1996 study of the discharge from the Kealakehe wastewater treatment plant. This data was analyzed by AECOS Laboratories, Hawaii. Samples were collected from the Visitor Center, Quarry, Well #2 and Well #6 using a peristaltic pump to prevent contamination. This program revealed that the natural groundwater in the Quarry well (upfield of the Harbor) has higher nutrient loads than the water entering the Harbor (Harbor Spring) indicating that tidal mixing is diluting nutrient loads.

Three groundwater wells were installed by the USGS in 1996. These wells were located inland of Aimakapa pond, inland of Kaloko Pond, and inland of and between the two ponds. These wells were used for water quality sampling on five separate occasions (Oki *et al*., 1999; Brock and Kam, 1997; Nance, 2000; Tribble, 2003; and Bienfang, unpubl.). Using these five sets of data, Hoover and Gold (2005) developed the nutrient vs. salinity curves shown for all three wells. These curves show a fairly constant relationship of salinity with nitrate, phosphate, ammonium and silica and fairly good agreement among the five sets of collected data. Using this relationship an inference of nutrient values for the salinity of the brackish inflow to the Harbor can be obtained.

In addition to this study, Johnson *et al*. (2006) presented similar curves of nutrients vs. salinity and also found a linear relationship with the exception of nitrate, which they assumed to be exponential. For the purposes of this analysis, a linear relationship is used for all nutrients as was described in Hoover and Gold (2005).

A comparison of values derived from these recent data sets were checked against each other. Note, however, that the values obtained from Hoover and Gold (2005) and Johnson *et al*. (2006) were estimated from the graphs and that the NO_3-N curve from Johnson *et al*. (2006) were linearized for the purposes of this analysis. In addition, chemical analysis of the groundwater by Bienfang (1980) indicates that it has a NO_3-N concentration of 35.7 µg-atom/L and a o-P concentration of 2.4 µg-atom/L.

The concentration of nutrients within the groundwater are quite high (Bienfang, 1980), and the tendency of Honokohau Harbor would be towards eutrophication. This is only prevented by the high rate of flushing which is 87% faster than the calculated tidal flushing (3.2 days) (OI Consultants, 1991). Bienfang (1980) also noted Honokohau Harbor's "isolation from other affecting forces, such as run-off, river/stream, or domestic/industrial sewage inputs." This indicates that the nutrient loads within the groundwater entering Honokohau Harbor originate upland of the WWTP. A simple analysis in Appendix C evaluates pathways of WWTP effluent through the ground.

Table 4-3: Groundwater conditions from four sources

	AECOS (2006 Harbor Spring)	Hoover and Gold (2005) (22 ppt)	Johnson *et al*. (2006) (22 ppt)	Bienfang (1980)
NO_3-N	420 µg-N/L	336 µg-N/L	434 µg-N/L	499.8 µg-N/L
PO_4-P	-	46.5 µg-P/L	58.9 µg-P/L	74.4 µg-P/L
NH_4-N	3 µg-N/L	14 µg-N/L	-	-
SiO_2-Si	15,800 µg-Si/L	8,960 µg-Si/L	8,960 µg-Si/L	-

From Table 4-3 it can be seen that the values collected and extrapolated from fitted curves are all similar in quantity and magnitude. A first test indicated that the values from AECOS (Waimea Water Services, Inc. 2006) were reasonable in terms of model performance, but that NH_4-N levels remained too small. Therefore, the value of incoming NH_4-N was increased to the value reported by Hoover and Gold (2005).

Table 4-4: Offshore and Groundwater Conditions

Constituent	Offshore condition	Groundwater Condition
Nitrate-nitrogen (NO_3)	21.13 µg-N/L	420 µg-N/L
Phosphate-phosphorous (PO_4)	2.97 µg-P/L	60 µg-P/L(lower)
Algae(non-Diatom)	0.008 mg C/L	0 µg/L
Diatom	0.0004 mg C/L	0 µg/L
Dissolved Silicon	312.87 µg-Si/L	10,000 µg-Si/L
Ammonia-nitrogen (NH_4)	1.43 µg-N/L	14 µg-N/L
Dissolved Oxygen	7.13 mg/L	4 mg/L

While there may be other nutrient loads to the system, it was beyond the scope of this model to be able to predict or calibrate to unknown loads. The incoming brackish groundwater parameter that was estimated or calibrated to the model was DO. The DO concentration was not reported by Waimea Water Services (1996), and measurements displayed in Hoover and Gold (2005) show a range of values of 5 to 8 mg-O/L. Bienfang (1980) reported values for DO of about 5 mg-O/L at the back of the basin, and so it is reasonable to use a lower concentration than 5 in the brackish water flowing from the back of the basin.

4.7 Existing Conditions

The water quality within Honokohau Harbor has been shown in previous studies (Ziemann, 2006 and OI Consultants, 1991) to be quite good. This is primarily attributed to the high rate of flushing within the Harbor. While in earlier years, water quality within the Harbor was affected by bilge discharges from boats, wastewater additions and other pollutants, the conditions currently seem to indicate that those sources have been decreased if not eliminated. The phosphorous loads on the system have apparently decreased between 1991 (OI Consultants, 1991) and 2006 (Ziemann, 2006). This is corroborated by the increase in the N:P ratio from approximately 6 to more than 15, indicating either a decrease in phosphorous loading or an increase in uptake by the resident algal population. An additional observation from all the datasets was a general decrease in concentration of nutrients at mid-Harbor, indicating a change in volume/bathymetry at approximately the location of the Harbor expansion (Phase I). An increase in nutrients near the Harbor mouth at approximately sampling station 7 (Ziemann 2006) tends to indicate an unidentified source. These broad conclusions about the change in water quality should be carefully considered because the data collected by Ziemann (2006) contains only one sample that may or may not represent a broad view of current conditions within Honokohau Harbor.

In order to calibrate the model to existing conditions, the calibration data points had to be determined. While the most recent data are preferable as descriptors of current conditions, the data were limited to one sample at each point. The less recent OI Consultants dataset (1991) was taken over a three month period with six total sets of data. This dataset was chosen, if only due to more reliable "typical" conditions. The 2006 data are used to provide additional verification as to the model's ability to predict these "typical" conditions. While the conditions and limiting nutrient may have changed since 1991, the trends and order of the model results are still reasonable.

Calibration of the model was performed with six different constituents ("benchmarks"): Silica (Si), NO_3-N, NH_4-N, o-P, DO, and Chlorophyll a. Due to the similarity of the station locations in 1991 and 2006, it was possible to compare some stations simultaneously with the model results. In these cases, the figures are labeled with Station 1/A, which indicates that the comparison is with Ziemann (2006) station 1, and OI Consultants (1991) Station A. The station locations are shown in Figure A-1 and Figure A-3 for Ziemann (2006) and OI Consultants (1991) respectively. However, a direct comparison is precluded because the surface samples were taken at differing depths.

The model used a certain amount of time to "spin up" or achieve quasi-steady state solutions to all of the processes involved. After this time period, which was about 10 days, the values of the model were extracted and averaged over the rest of the model run. Each model was run for a 1 ½ month period. The resulting means and standard deviations are compared to the geometric means of the OI Consultants (1991) datasets and the values obtained by Ziemann (2006). Note that the model standard deviation is only representative of the daily and tidal variability. OI Consultants (1991) took samples at three depths; however, due to changes in bathymetry or conditions on the day of sampling, some of the depths are below the model depth which is zero at MSL. Points which are not displayed fell outside the range that is shown on the figure. These points represent either aberrations in data or inability of the model to predict the large sample

variability. Average model results are shown as black solid lines, with the standard deviation shown as a dotted line. OI Consultants (1991) geometric mean data is shown as red circles, while Ziemann (2006) data is shown as blue circles. Ziemann (2006) took data points at 0.3 m from the surface and 0.5 m from the bottom (at unspecified tidal cycles) while OI (1991) sampled at 0.5 m from the surface, 1.5 m and 3.0 m from the surface for ebb and flood tides.

4.7.1 Silica (Si)

Silica concentrations within Honokohau Harbor changed between 1991 and 2006. The values obtained in 2006 are higher than those collected in 1991. This is especially evident in the surface layer. Figure 4-1 shows the calibration for the silica model results and data. The model performed well by correctly simulating the vertical distribution and magnitude of the depth variability; however, the differences between 1991 and 2006 were too extreme to be captured by the model. Similarly to the other nutrients discussed in the following sections, silica is present in high quantities in the upper layer throughout the existing Harbor .Silica concentrations were highest at the back of the Harbor and decreasing toward the mouth, establishing groundwater as the loading source. The lower layers tend to have either more "clean" sea water or more diatoms that consume the silica. Therefore, concentrations in these layers tend to be less. However, the concentrations of silica in the Harbor increased significantly from 1991 to the 2006 measurements. This would tend to imply a shift in the algal populations away from silica consumers (diatoms), co-incident with the overall system shift from nitrogen-limited to phosphorous-limited.

4.7.2 Nitrate-nitrogen (NO_3-N)

NO_3-N concentrations within Honokohau Harbor also changed between 1991 and 2006. This is indicated by the apparent system shift from nitrogen-limited to phosphorous-limited, leaving excess inconsumable NO_3-N. However, the values are not very different. They are still within the same order of magnitude, and the model matches that magnitude along with the vertical distribution (Figure 4-2). Higher NO_3-N concentrations are found in the surface layer, where there are fewer phytoplankton to consume it. Deeper in the water column, more phytoplankton are present due to slower velocities and warmer temperatures. Stations closer to the Harbor entrance have a more drastic vertical distribution due to the influx of "clean" sea water in the lower layers and the high nutrient brackish water in the upper layers. Again, there is an apparent decrease in concentration in surface samples mid-Harbor (possibly indicating a change in volume or bathymetry that would dilute the load of NO_3-N) and an increase near the mouth (indicating an unidentified source at that location).

4.7.3 Ortho-phosphate (o-P)

The axial and vertical distribution of o-P follows the trends of both nitrate-nitrogen and silica, since it is subject to similar effects. Concentrations were higher in surface samples at the back of the Harbor and generally become lower due to dilution and consumption. A spike in concentration near the Harbor mouth (Ziemann (2006) station 7) implies an additional and unidentified load is entering near the Harbor mouth. The model performs well in replicating this distribution. The o-P concentrations are significantly lower in 2006; however these levels are still within the same order of magnitude of the values collected in 1991.

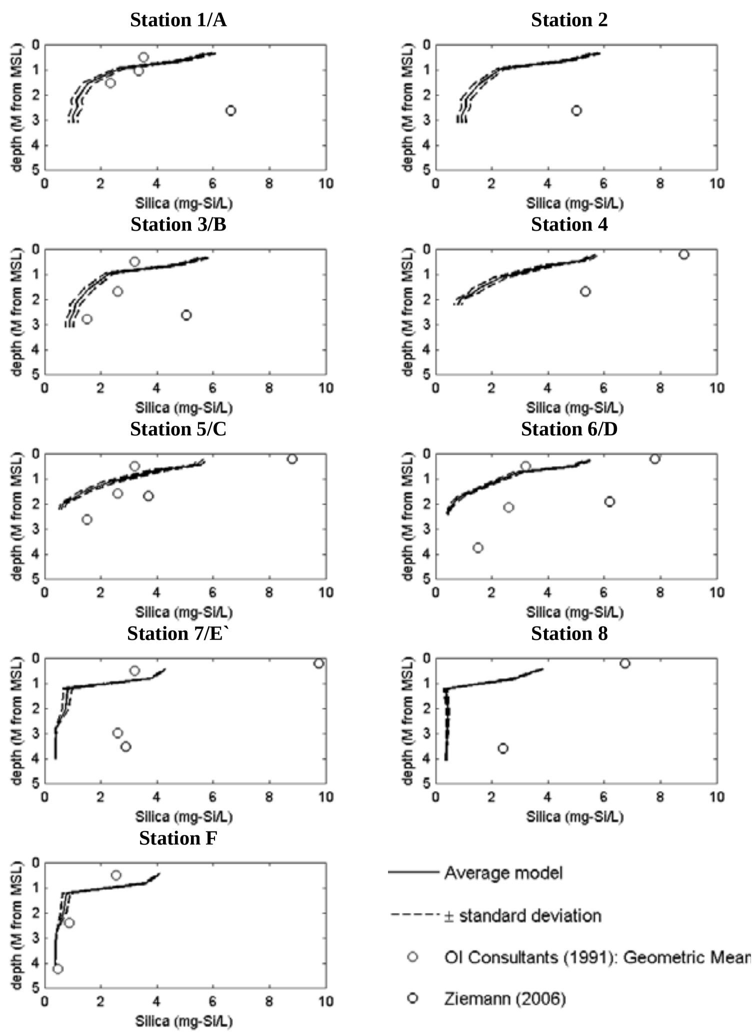

Figure 4-1: Silica (Si) calibration

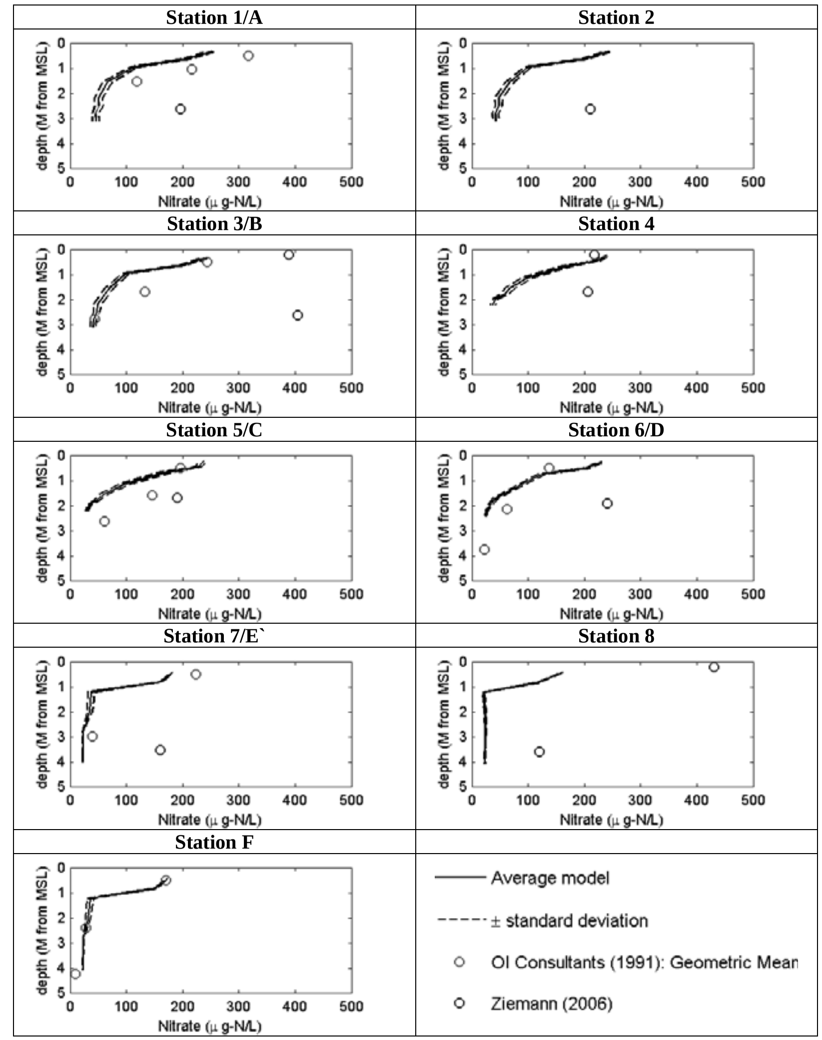

Figure 4-2: NO_3-N calibration

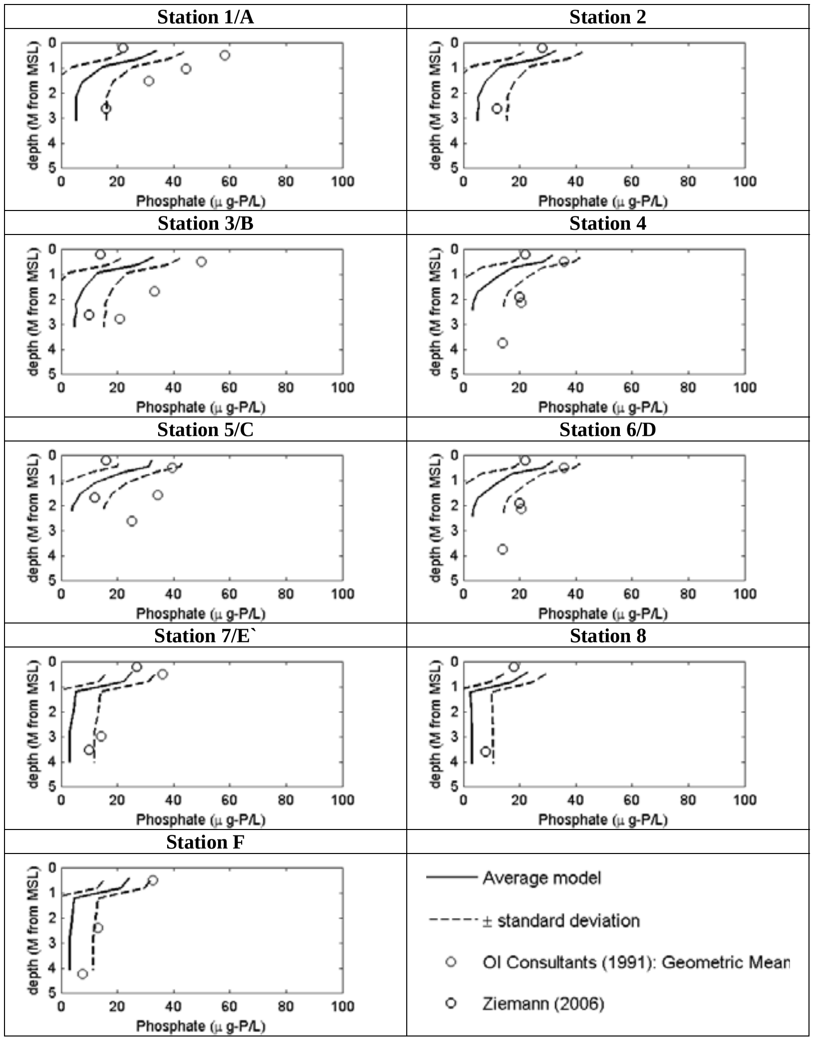

Figure 4-3: o-P calibration

4.7.4 *Ammonia-nitrogen (NH_4-N)*

The ammonia-nitrogen load into the system is fairly small and seems to agree well with the data. From both 2006 and 1991 (Figure 4-4), the vertical distribution is similar to the other nutrients presented and the model seems to perform well with this distribution. However, in the calibration, ammonium is underestimated at all stations, indicating that loading of the constituent (described in datasets) is insufficient. Corroborating evidence was found in the co-incident overestimation in DO at all Harbor stations. Given the slightly higher values of ammonium-nitrogen in 1991, it is apparent that a shift in loading has occurred, possibly from improvements in a nearby wastewater treatment system. Coincidentally, the DO deficit has also improved significantly from 1991 to 2006, verifying that reductions have occurred in ammonium loading.

The significant increase in concentration measured in the 1991 data set indicates that an additional load may have been introduced between Ziemann (2006) stations 4 and 5. This location corresponds to a restroom that is treated by septic tanks and discharged into the groundwater (Hoover and Gold, 2005). It is presumed that this immediately flows into the existing Harbor, causing a significant ammonia-nitrogen increase as well as a subsequent change in the DO content within the water column. This was tested within the model by adding an additional ammonia load at this point in the model to examine the effects. Figure 4-5 shows the results of the model including this additional load. However, this test load is not considered in the subsequent future conditions section, as it is stated in the EIS submitted on 15 June 2007 that all sewage currently treated by septic tanks will be rerouted to the wastewater treatment plant as part of the project.

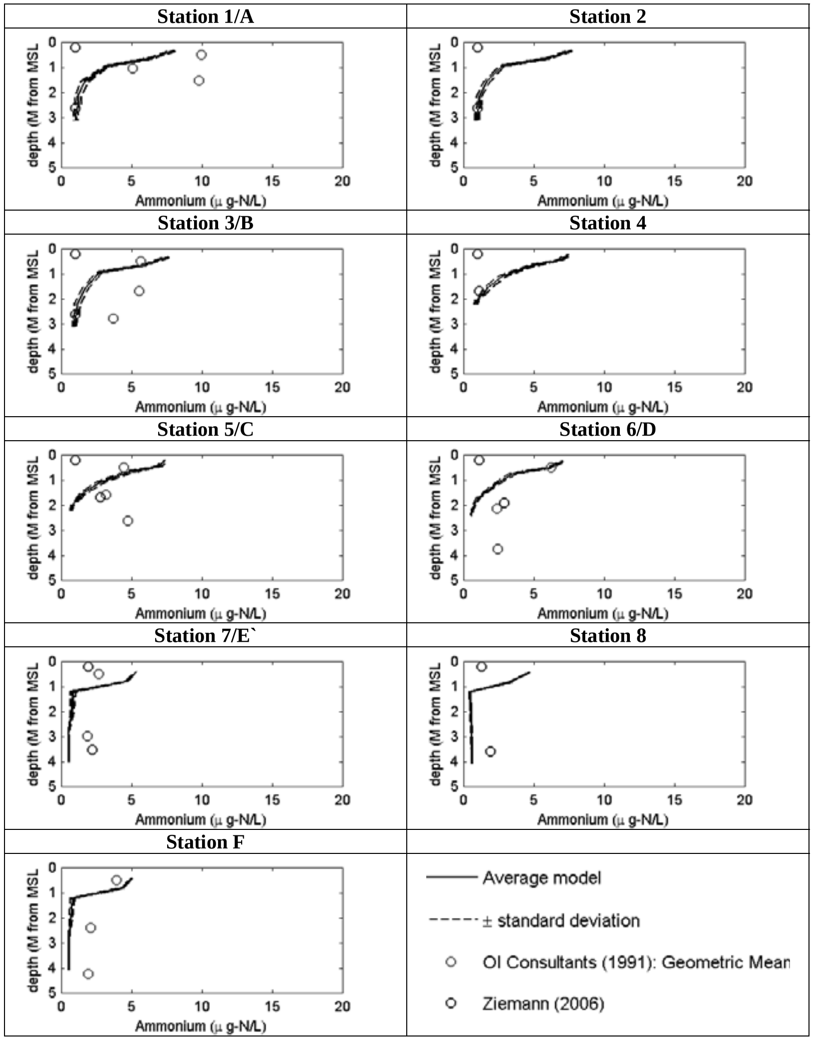

Figure 4-4: NH_4-N calibration

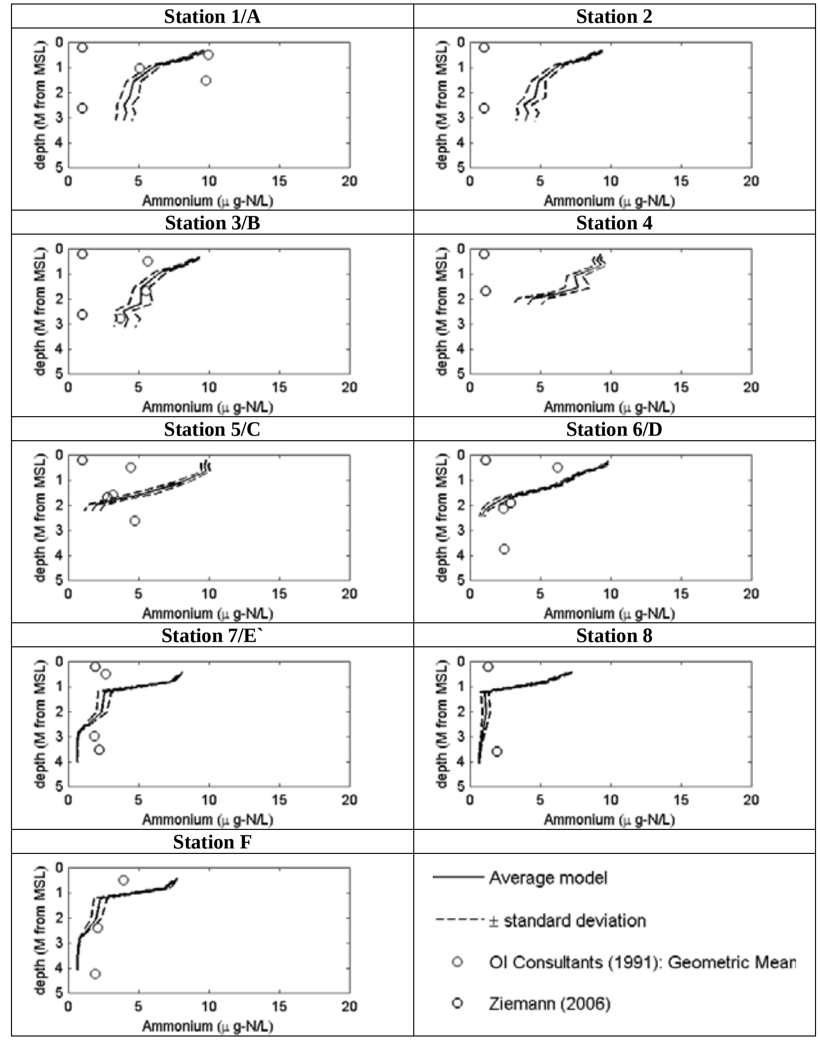

Figure 4-5: NH_4-N with extra load

4.7.5 *Dissolved Oxygen (DO)*

The DO profiles (Figure 4-6) show that the DO concentrations are lowest at the surface with the low oxygen content coming from the groundwater. As the water gets deeper and there are more phytoplankton growing and producing oxygen and more saline ocean water with DO values around 7.1, the oxygen content gets higher. This seems to corroborate the data from both 1991 and 2006. While the 2006 DO measurements are slightly lower than the data presented in 1991, the DO deficit is actually lower (DO is a function of salinity and temperature), indicating that there has been overall improvement of (i.e., a decrease in) DO-demanding loads in the Harbor since 1991. However, the calibration of DO is overestimated at most of the stations, providing insight that an additional and unknown oxygen-demanding load is not being addressed.

The extra load of ammonia that was discussed in section 4.7.4 is another sink of DO, requiring 4.57 g-O/L per g-N/L. The effect of this was minimal in terms of the vertical distribution of DO within the water column. To avoid repetition, the additional plots are not shown. Since the input of ammonia-nitrogen due to the restroom inflow was 14 µg-N/L, under maximum oxidation, it would only impact the DO by 0.06 mg-O/L, which is not resolvable in the calibration plots. However, it is worth noting, that this effect does exist, and the greater the NH_4-N load on the system, the greater the impact on the DO concentration.

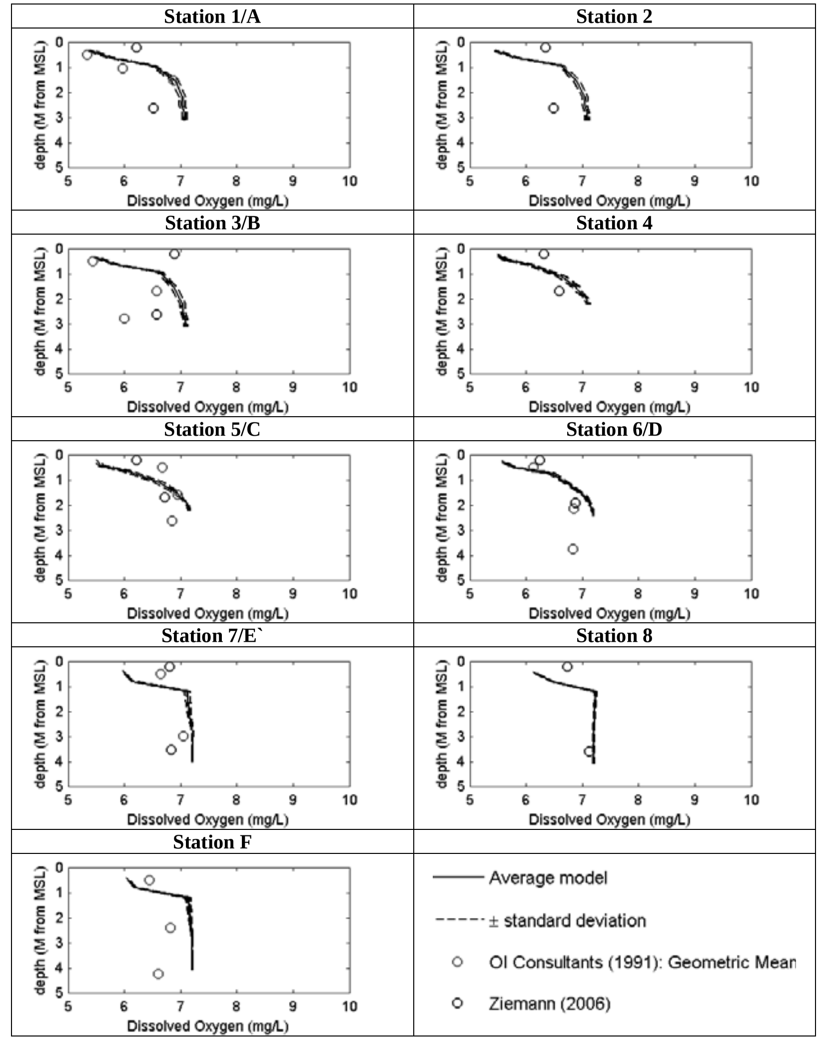

Figure 4-6: DO calibration

4.7.6 *Chlorophyll a (CHLa)*

Chlorophyll concentrations were extremely variable, especially within the OI Consultants (1991) datasets. Extremely high values were observed at Stations B and C that were too large to fit within the data represented by Figure 4-8. These large values were not replicated in the data collected by Ziemann (2006). The chlorophyll curves that were generated with the model follow the vertical distribution shown by the data and as observed in Bienfang (1982) and OI Consultants (1991). They describe the main vertical position of the algae to be centered in the middle layer of the existing Harbor due to the unfavorable conditions in the top layer (low salinity and temperature), and the light penetration constraint nearer to the bottom of the Harbor (Figure 4-7).

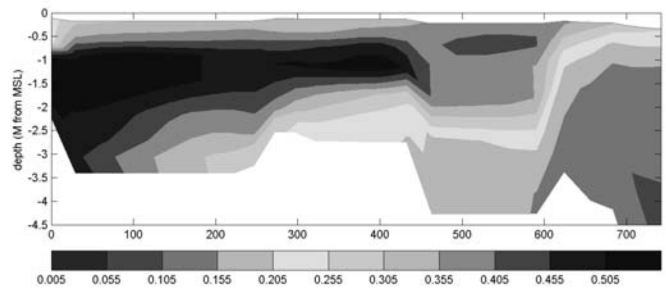

Figure 4-7: Algae concentration (µg –CHL a/L) along Transect EH (Figure 3-12)

It is seen that the chlorophyll has much higher values in the interior of the basin, especially in the middle layer. Nearer to the harbor mouth, the oceanic water dominates the bottom layer and there is less phytoplankton growth. This is also observed in the depth profiles in Figure 4-8, where in the interior basin, the maximum chlorophyll values are in the middle layer of the inner basin. The outer basin has much more stratified layer.

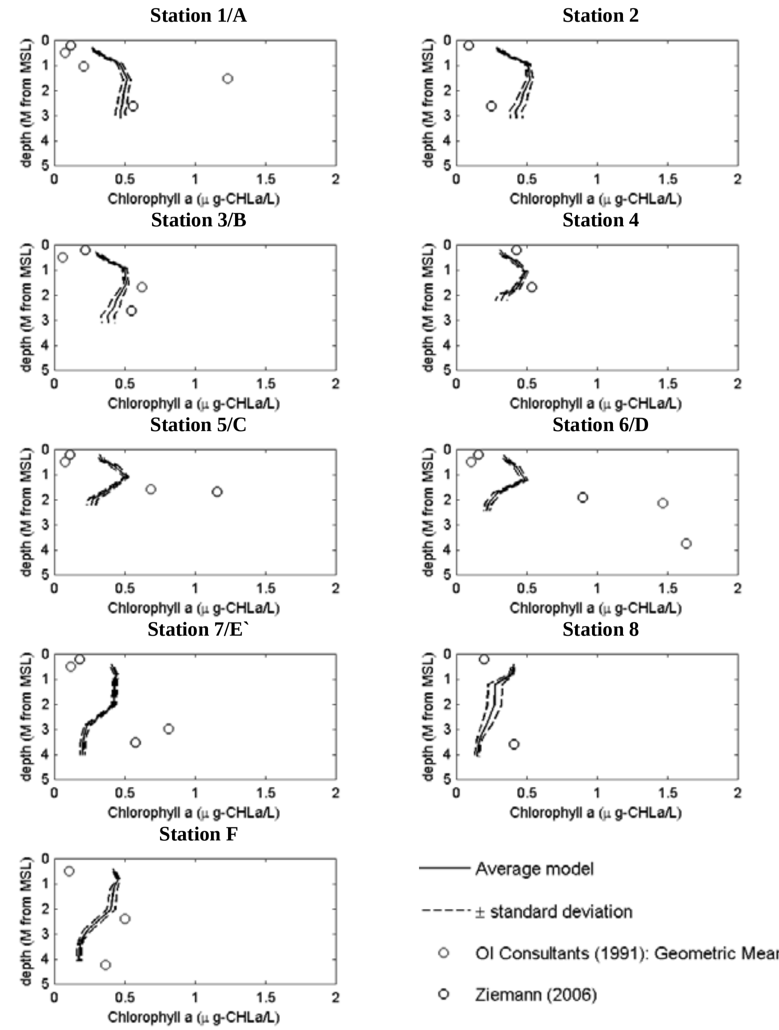

Figure 4-8: Chlorophyll a calibration

Concentrations of benchmark constituents (NO_3-N, o-P, NH_4-N, Chlorophyll a and DO deficit) calibrate well at the back and mouth of the Harbor. This implies that the flushing volume and time, as well as constituent loads, were adequately quantified during calibration. Table 4-5 shows the comparison of the model results with the data variability. It can be seen that in all cases the model difference was less than or equal to the standard deviation of the data, which indicates that the model performance is reasonable.

Table 4-5: Model agreement with data

	Model difference from data (maximum) (1991)	**Standard Deviation (data, 1991)**	**Model difference from data (maximum) (2006)**
Silica (mg-Si/L)	2.20	3.19	5.48
Nitrate (mg-N/L)	0.11	0.67	0.46
Ortho-Phosphate (mg-P/L)	0.03	0.03	0.02
Chlorophyll a (mg – CHLa/L)	0.005	0.006	0.0008
Dissolved Oxygen (mg-O/L)	1.09	1.31	1.42
Ammonium (mg-N/L)	0.01	0.01	0.01

4.8 Future Conditions

The following assumptions were made in the determination of future performance of the Honokohau and Kona Kai Ola Marina system. These assumptions were both necessary and appropriate for the typical conditions simulated.

Wastewater Treatment Plant (WWTP) influence on the Groundwater: The high nutrient loads entering the harbor system through the groundwater are not likely to decrease from those observed in the existing Harbor, and therefore it is necessary to find a project alternative that primarily reduces the flushing time within the system to a level that will successfully expel the nutrient laden water from the system. In addition, nutrient levels in the groundwater are considered to be the same as those in the brackish groundwater entering the existing Harbor. Although nutrient levels in Well #6 (Waimea Water Services, 2006) located near the future location of the new Marina are higher than those in the brackish water entering the existing Harbor, the higher levels are likely a direct influence of the WWTP. It is assumed that nutrient levels in the brackish groundwater entering the new Marina will be similar to those entering the existing Harbor, which correspond to groundwater unaffected by the WWTP inflow (see Appendix C). To achieve these conditions the WWTP will be upgraded to tertiary treatment.

Additional point or nonpoint sources into the new Marina: It is assumed that the project will implement point and nonpoint source water pollution control measures. Therefore, simulations included in this study do not include any additional sources. If these control measures were not implemented and additional sources of nutrients are allowed to enter the new marina, results presented in this report could not represent future conditions.

Groundwater consumption: It is assumed that no additional groundwater will have to be withdrawn from the aquifer to be used in the new development and therefore the groundwater levels and volumes will remain the same as existing conditions. Groundwater withdrawal will likely decrease the amount of brackish water reaching the harbor system and coastline. Oki et al. (1999) modeled this reduction using a three-dimensional groundwater model, and found that the decrease in freshwater discharge within the Kaloko-Honokohau National Historical Park could be as much as 0.44 mgd of fresh groundwater. This was obtained by increasing withdrawals upland by about 1.6 mgd. If water is withdrawn from the aquifer it may alter the current amount of brackish groundwater entering Honokohau Harbor. A full groundwater study complete with a three-dimensional, tidally-coupled, variable density groundwater model would be needed to project these effects on existing and proposed conditions.

Groundwater brackish inflow: Since the exact quantity of brackish groundwater inflow to the new Marina is unknown, this value was bracketed between the values of 0 and 60 mgd as in the previous section. Ziemman (2006) indicated that the new Marina will capture brackish groundwater flow that is currently flowing towards some ponds and areas with vegetation downstream of the location of the new Marina. In addition Waimea Water Services (2007) states that a significant quantity of brackish water will be intercepted by the new Marina. Therefore, although the exact amount of brackish groundwater that will be intercepted by the new Marina is unknown, it seems that some amount will be flowing into the new Marina. The effects to the downstream ponds is unknown without a quantity of intercepted groundwater. While some of the solutions shown in the following sections provide adequate water quality conditions post-expansion, it is worth noting that one of the major controlling factors is the brackish groundwater inflow, and without an accurate estimate of this value, a reliable prediction of post-expansion conditions cannot be obtained. In order to estimate the intercepted brackish groundwater flow by the new Marina, a more detailed monitoring effort would be required. This effort will also be used to determine the density differences spatially and in depths below the surface. A tidally coupled variable density groundwater model would also be recommended and would be beneficial to determine the effects of the new Marina construction.

Exhibit Discharge: Discharge from the water exhibits includes nutrient loadings calculated as a function of the marine animal present in the exhibits. The water drawn from the ocean for the marine exhibits was taken from a 100 m depth offshore. This water is drawn approximately along the line of Transect D in Figure 4-9 at 500 m from shore. Due to its depth, at pumping, the temperature of the water is about 3 degrees less than surface water, and this is assumed to increase approximately 1 degree during its retention in the exhibit area. Nutrient loads were determined using a feed ratio of 2% of the population body weight (502 kg/day), and computing the quantity of ammonia-nitrogen (15.06 kg/day) and suspended solids (150.62 kg/day) related to this feed ratio. This resulted in a total ammonia-nitrogen concentration of 53.8 µg-N/L in the exhibit flow entering the new Marina. All computations with regard to the exhibit flow were performed by ClowardH2O (2007) and are documented in Appendix D.

The exhibit also introduces a load of total suspended solids which represents a certain unknown quantity of Carbonaceous Biochemical Oxygen Demand (CBOD) that could further impact the DO. However, results show that the overall impact on the DO in the system is fairly minimal due to the large amount of water inflow with high Dissolved Oxygen concentrations and the high levels of primary production. In addition, compared to the oxygen demand required to satisfy the nitrogenous BOD (NBOD) load coming from the ammonia-nitrogen, the oxygen demand for carbonaceous load is expected to be minimal.

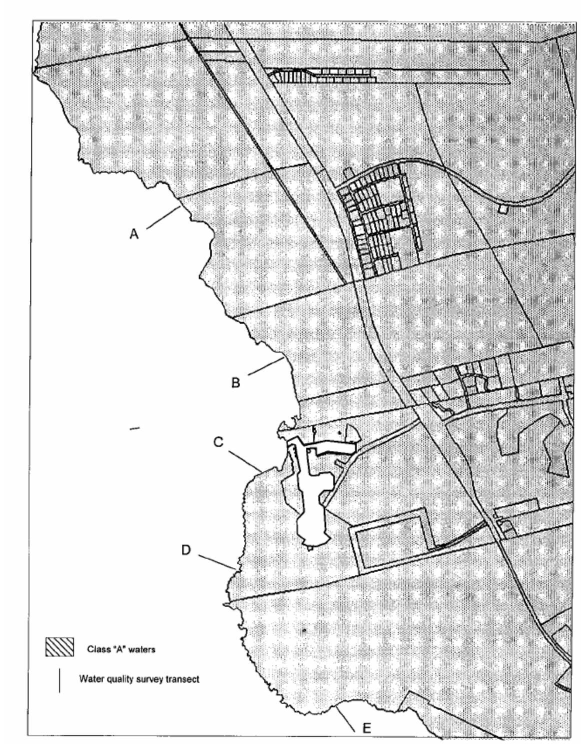

Figure 4-9: Transect location (Ziemann, 2006)

4.8.1 Nutrients

As presented in Section 3.3.4, for all projected scenarios, flushing time is increased, thus, algal residence time is increased within the Harbor. As phytoplankton spend more time within the Harbor without being flushed out, they are able to consume more nutrients. To determine the limiting nutrient under the new conditions, the ratio of nitrogen to phosphorous (N:P) is examined in (Table 4-6). It is shown that the system containing the new Marina is phosphorous-limited. As more o-P is introduced with the brackish groundwater, the N:P ratio decreases but still remains phosphorous-limited. Further discussion of the phosphorous limitation is found in 5.4.2.

Table 4-6: Nitrogen to Phosphorous (N:P) ratio inside existing harbor

Case	N:P ratio within existing harbor	N:P ratio at harbor mouth
Discharge 0 mgd	10.8	8.8
Discharge 15 mgd	8.6	8.2
Discharge 30 mgd	8.3	8.2
Discharge 60 mgd	8.0	8.0

Under low brackish inflow conditions, the addition of phosphorous to the system is immediately utilized. This is compounded by the fact that the need for nutrients is greater due to the longer period of time that phytoplankton remain within the system. It can be seen from Figure 4-10 and Figure 4-11 that the nutrient levels within the existing harbor are depleted much more in all of the future cases than they are under existing conditions. It is also worth noting, that the NO_3-N concentration is reduced more with increasing brackish groundwater discharge (indicating more utilization), because of increased loading of the limiting nutrient, o-P. This is corroborated by examining the o-P concentrations by loading scenario: o-P concentrations are depleted the most with 0 mgd of brackish groundwater inflow, and concentrations increase with higher loadings of brackish groundwater. This not only supports the argument of the phosphorous-limitation on the system, but also indicates that there is sufficient NO_3-N within the system to continue to support more influx of o-P and subsequently more phytoplankton production.

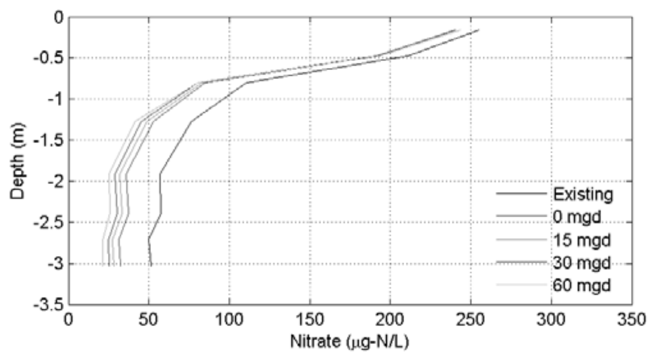

Figure 4-10: NO_3-N concentrations in inner existing Harbor (Figure 3-12)

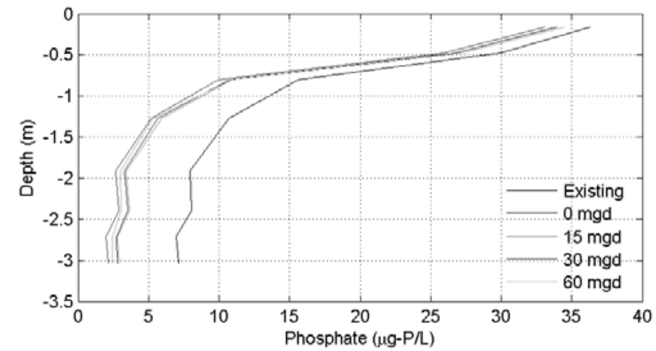

Figure 4-11: o-P concentrations in inner existing Harbor (Figure 3-12)

While this may result in a decrease in NO_3-N and o-P concentrations, it may increase the total nitrogen and total phosphorous loads to the system due to production of N and P substances with the death of phytoplankton.

Due to the phosphorous limitation on the system described, the ammonia introduced from the exhibit flow does not significantly affect the chlorophyll production within the system, as will be shown in a later section. This is not to say that this inflow does not affect the water quality within the system. The load is a significant DO sink, and it causes the system to be even more phosphorous deprived. This deprivation can lead to problems as any new phosphorous source can cause a significant algal bloom.

4.8.2 Dissolved Oxygen

The NBOD load being exerted by the incoming exhibit flow is equivalent to 0.28 mg-O/L. However, due to the high DO content in the exhibit discharges, the model predicts that this load will not adversely affect the DO concentrations. Modeling of the DO within the system shows a daily variability, due to the consumption without production during the nighttime, however the concentration of DO never drops to levels that would be considered problematic. This is due to the high concentration of oxygen in the exhibit flow in combination with the oceanic circulation. It appears that even with the NBOD load, the system remains aerobic. Water quality standards for Hawaii require that the DO remain >75% of the saturation DO for the specific temperature and salinity regime, so that even aerobic systems may violate the State water quality standard. Current data (Ziemann 2006) indicate that the Harbor DO concentrations are approximately equal to DOSat; thus, additional BOD loads should be carefully assessed for impacts to assure compliance with state water quality standards. It is noted that CBOD loads that were not accounted for within the model could do much to impact the DO concentrations in the exhibits and consequently, in the Harbor.

The indicators of phosphorous limitation in section 4.8.1 and the chlorophyll values described in the following section all lead to the conclusion that there will be sufficient algal response from the exhibit-loaded nutrients to affect mesotrophic and possibly eutrophic conditions within the Harbor. Under these conditions, the concentration of DO in the system is likely to decrease significantly, although this is not shown by the model. With a significant increase in algal population, nutrient cycling may effect a substantial re-loading of ammonium back into the water column from bacterial activity at the sediment: water interface[17] resulting in additional NBOD demands on the Harbor DO concentrations. These processes were not included within the existing model due to their relative unimportance within the context of the existing water quality system.

4.8.3 Chlorophyll a

The major focus in the modeling of the system was to project the trophic state of the Harbor following the construction of the new Marina. As discussed in Section 3.3.4, the flushing time of the existing Harbor increased by almost double in most cases due to internal circulation between the new Marina and the existing Harbor. This immediately presents the possibility that the algae growth within the existing Harbor may increase, due to the increased phytoplankton residence time in the Harbor. In addition, the internal circulation is projected to transfer algae and nutrients between the two harbors, without expelling those substances into the ocean. Another problematic factor is that there is also a constant input of phytoplankton and nutrients from the exhibit discharge. All of these factors contribute to increased phytoplankton growth and a potentially eutrophic situation.

Simulation results indicate that increases could be on the order of 10 to 50 times the amount of chlorophyll present under existing conditions (< 1 µg-CHLa/L). Figure 4-12 through Figure 4-15 show the changes in Chlorophyll a concentration within the existing Harbor. It can be seen that significant changes occur throughout the existing Harbor and are not limited to areas adjacent to the new Marina. Despite the decreased flushing time with increased brackish water inflow, conditions are worsened with the largest brackish groundwater discharge simulated, with concentrations 7-8 µg-CHLa/L higher under the new conditions. This is due to the higher nutrient load added by this brackish groundwater inflow. In addition, since the new system is phosphorous-limited, any addition of phosphorous to the system will be immediately consumed by the phytoplankton and will cause rapid growth.

[17] Substantial increases in organic nitrogen loading from death of the larger phytoplankton population result in subsequent settling and accumulation on the bottom. This thicker layer of organic material at the bottom causes effects such as mineralization and denitrification to become important, which can impact the DO significantly within the system.

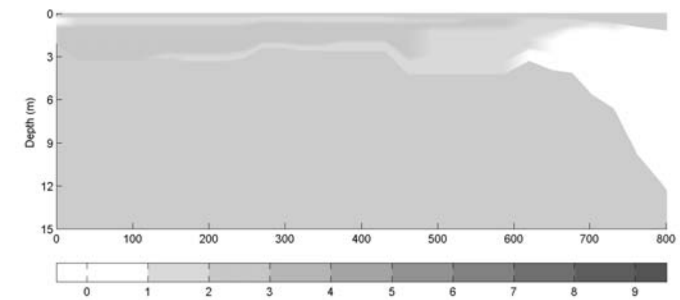

Figure 4-12: Change in Chlorophyll a concentrations (µg-CHLa/L) along Transect EH for 0 mgd brackish discharge

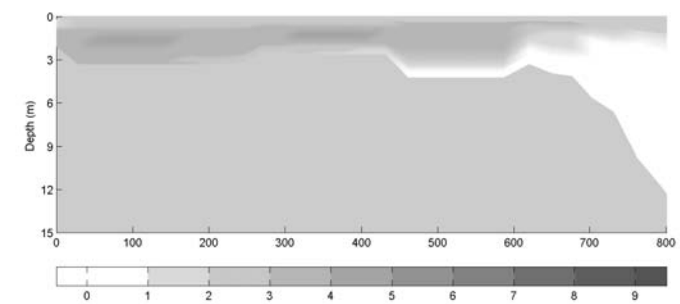

Figure 4-13: Change in Chlorophyll a concentrations (µg-CHLa/L) along Transect EH for 15 mgd brackish discharge

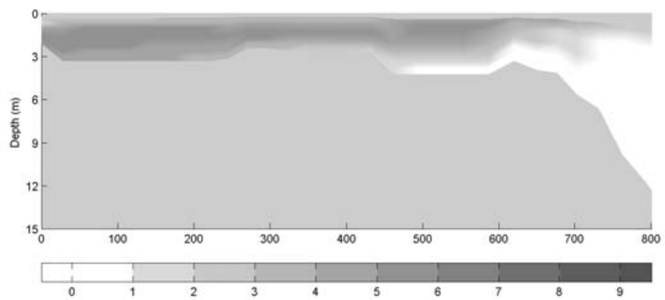

Figure 4-14: Change in Chlorophyll a concentrations (µg-CHLa/L) along Transect EH for 30 mgd brackish discharge

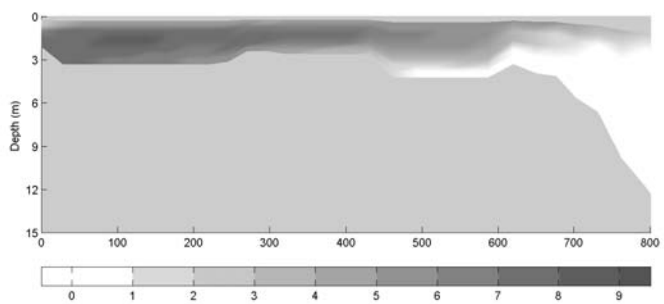

Figure 4-15: Change in Chlorophyll a concentrations (µg-CHLa/L) along Transect EH for 60 mgd brackish discharge

In addition to the increase in flushing time, exhibit and brackish groundwater loads are projected to cause a substantial shift in the system. The water quality within the existing basin becomes degraded as planktonic growth increases. Thomann and Mueller (1987) define a eutrophic system to be one which has chlorophyll values in excess of 10 µg-CHLa/L. For the simulated scenarios, the model-projected conditions will degrade to a mesotrophic level with chlorophyll levels consistently within the range of 4-10 µg-CHLa/L. The resulting increase in chlorophyll levels in the existing harbor may be as high as 8 µg-CHLa/L. The existing system is very oligotrophic with chlorophyll levels remaining below 0.5 µg-CHLa/L. The high levels of Chlorophyll a and the system's sensitivity to phosphorous inputs indicate that with any new point or non-point loads containing phosphorous could advance the system from mesotrophic to eutrophic conditions

It should be noted that conditions reported in both Bienfang (1982) and OI Consultants (1991) reported high values of Chlorophyll a in isolated regions or at specific times; however the model

projections predict that under the typical conditions simulated, almost all locations will have Chlorophyll a values in excess of 4 µg-CHLa/L, the boundary for mesotrophic conditions. Therefore, it stands to reason that during certain times of year, these levels could be much higher.

The only condition that limits the phytoplankton population significantly enough to keep the existing Harbor and new Marina oligotrophic is the condition where the brackish groundwater discharge is 0 mgd. In this case, the o-P concentrations are so small, that the phytoplankton growth is limited by this condition. However, this is not a probable condition due to the high porosity of the rock in the project site, and could only be achieved if the entire new Marina were lined. It is worth noting that even under these conditions any point or non-point sources of o-P would immediately trigger phytoplankton growth, and due to the high flushing time, this would reach undesirable conditions quickly.

The impacts of this change in system dynamics also extend offshore, as the algae and diatoms are carried out of the Harbor. OI Consultants (1991) and Maragos (1983) have shown that coral communities have continued to be established within the Harbor even with the extensions. OI Consultants (1991) reported that the coral population increased from 2.3% to 6.3% between 1981 and 1991 (mostly within the outer harbor).[18] The potential for eutrophication within Honokohau Harbor and the proposed Kona Kai Ola Marina could cause damage to the existing coral populations within Honokohau Harbor and inhibit further growth (Costa *et al*., 2000).

Within the new Marina, there are significant phytoplankton populations that are especially prevalent in the back basin (Figure 4-16 through Figure 4-19). This area of the new Marina has the longest flushing time and is the most saline region of the basin. The water quality in this region may be improved with the introduction of a piped water source coming into the new Marina at a certain flow rate to enhance circulation; however due to the high nutrient levels in the inflow, it is suspected that without a significant reduction in flushing time, the phytoplankton production will remain a problem throughout the new Marina.

[18] In earlier discussions, it is surmised that a population shift may have occurred between the diatoms and phytoplankton. The increased concentration of silica in the Harbor (Ziemann 2006) may indicate that diatom populations have decreased under the phosphorous-limited regime (thus, less uptake of silica). Thus, a small increase in phosphorous may restore the balance of diatoms:phytoplankton, yet the projected water quality degradation from increased nutrients, may mask any benefit to the population dynamics.

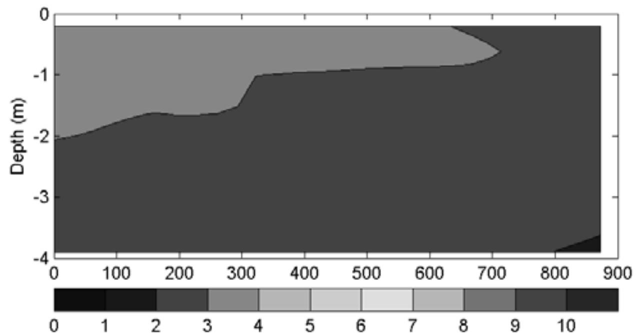

Figure 4-16: Chlorophyll a concentration (µg-CHLa/L) along Transect with brackish inflow of 0 mgd.

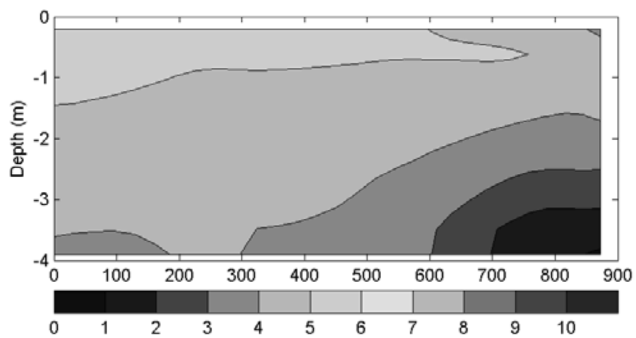

Figure 4-17: Chlorophyll a concentration (µg-CHLa/L) along Transect NM with brackish inflow of 15 mgd.

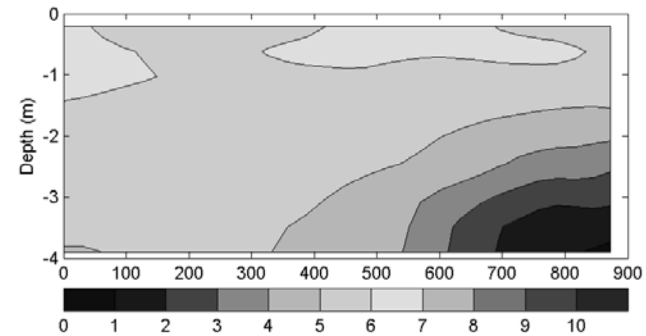

Figure 4-18: Chlorophyll a concentrations (µg-CHLa/L) along Transect NM with brackish inflow of 30 mgd.

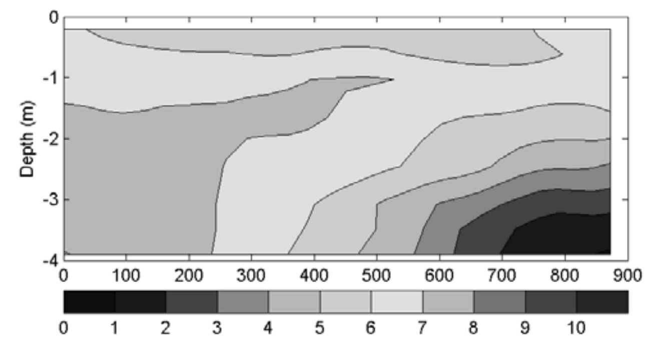

Figure 4-19: Chlorophyll concentrations (µg-CHLa/L) along Transect NM with brackish inflow of 60 mgd.

In addition, the projected chlorophyll leaving the harbor in the upper layers is in much higher concentrations than were found under existing conditions. This will affect the turbidity of the water significantly, as Bienfang (1982) attributed the turbidity within the Harbor to phytoplankton production. Outside of the Harbor, the waters also experience a change in Chlorophyll a concentration in the upper layers. This is important, as it will affect the light entering the water column and may impact biological systems in the nearby area. Figure 4-20 shows the vertical profiles of chlorophyll in the position of station J (OI Consultants, 1991), which is at about the 10 m depth contour outside of the harbor mouth. It can be seen that the surface layers of chlorophyll change significantly with the addition of the new Marina. At lower depths, the change is very slight.

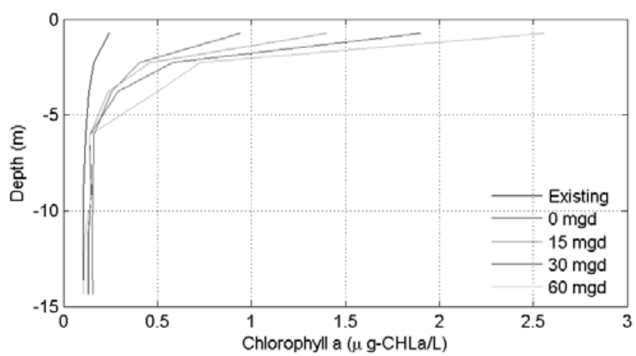

Figure 4-20: Chlorophyll profile outside of Honokohau Harbor (Station J Figure 3-12)

The conditions that were described in the previous section are shown to have unacceptable water quality conditions for all of the bracketed brackish groundwater conditions. Due to the fact that the nutrient loads within the new Marina are phosphorous limited post-expansion, it also indicates that the loads from the exhibit waters are likely not the cause of the additional algae growth within the system. This is further investigated in the following chapter. Since it is not feasible to control or treat the loads coming through the brackish groundwater, it is necessary to find an alternative that will increase the flushing of the new Marina and existing Harbor. The flushing is impaired in the above scenarios due to the internal circulation that exists between the two basins. It is necessary to control this circulation to keep the system flushing and decrease the time spent within the new Marina and existing Harbor by nutrients and algae.

5. ALTERNATIVES TO THE CONCEPTUAL MASTER PLAN

Results presented in the previous section suggested that for the new 45-acre Marina included in the conceptual Master Plan, the existing water quality conditions at Honokohau Harbor could not be maintained in the future two marina system, within the groundwater inflow ranges that were assumed in this study. If the inflow is determined to be greater than 60 mgd, the proposed Marina could be reevaluated. Therefore, it is necessary to examine alternatives to the proposed plan in order to find a solution that is not detrimental to the existing and future harbor system and surrounding waters.

Due to the limiting and unique conditions experienced in Honokohau Harbor and its environs, the mitigation alternatives are required to be unique. As was discussed in Section 3.3.5, a significant impact that occurs with the construction of the new Marina is the introduction of internal circulation between the two Marinas. In order to improve flushing and water quality, it is recommended that this internal circulation is minimized in order to separate the system into 2-layer systems that mimic the pumping that currently exists. The EPA's recommended Best Management Practices for increasing flushing of marinas suggest a number of different options (EPA, 2001: Section 4.1).

- Changing the size or shape of the entrance channel,
- Adding more than one entrance channel,
- Using mechanical aerators in problem areas,
- Optimizing the geometry such that there are as few separated basins as possible, and
- Changing the size of the basin.

The use of mechanical aerators is likely ineffective if not harmful to flushing enhancement in this system. While mechanical aerators may increase the amount of oxygen within the system, they will also vertically mix the system degrading the density stratification that is driving the current flushing. It will also mix nutrients into the bottom layers, which causes concerns for the native coral populations.

The change in size of the new marina is investigated at length in the following sections. Another unique alternative to this system would be to alter the controllable inputs to the system, such as the exhibit outfalls. The placement and inclusion of these outfalls is also investigated in the following sections.

Any further investigation of alternatives needs to be prefaced with an estimation of the inflow of groundwater to the system. Previous and future sections of this report demonstrate the controlling influence of this inflow on both flushing and nutrient loads. Further mitigation investigations will be subject to this estimation.

Adding another entrance channel to the new Marina also was not investigated. The possibility of making the Kona Kai Ola extension an entirely separate entity, leaving Honokohau Harbor entirely intact is another potential solution that could be considered. In this scenario, the internal circulation between the two marinas would be negated, allowing each to function independently.

In this scenario, it is possible that both will flush sufficiently. This option would still depend primarily on the influx of brackish groundwater.

EPA's Best Management Practices (EPA, 2001, Section 4.1) also stress the importance of harbor geometry to flushing. It also claims that the less semi-separated basins a marina contains, the faster the flushing. This was exemplified in the previous chapter's discussion on the internal circulation effects. Due to the geometry of the linkage between Honokohau and Kona Kai Ola Marina which are essentially separated basins with a connection, the circulation between the two marinas was complex and destructive to the water quality. It is likely that if the new Marina was positioned such that it was in line with Honokohau Harbor (like a large box), the flushing of the total system would be improved.

While all of these practices have the potential for improved water quality, the most appropriate practice, or combination thereof, is still dependant on the quantity of brackish groundwater expected to enter the new Marina.

5.1 Assumptions

The assumptions made in order to asses future conditions in Kona Kai Ola Marina (Section 3.3) were maintained for the Alternative analysis.

5.2 Simulated Scenarios

The calibrated hydrodynamics and water quality models described in Chapters 3 and 4 were applied to simulate future conditions for each of the considered alternatives. In this particular application, alternatives were limited to varying the size of the new Marina and the placement of the exhibit discharge; this is due to the computational demands of each test and the need to vary the unknown brackish inflow. In the future, the model could also be used for other alternatives not considered in this study. Table 5-1 and Table 5-2 show the significant computational effort conducted as part of this study. Simulations from Table 5-1, which considered an 800 slip marina as described in the Conceptual Master Plan, were discussed in the previous section with the exception of cases 9 and 10 that consider an alternative location for the exhibit flow outfall.

Table 5-1: Scenarios for 800 slip new Marina

Proposed Harbor Size (800 slips)		
Simulation number	Quantity of Brackish Discharge	Location of Exhibit Discharge
1	0	Back of New Marina
2	15	Back of New Marina
3	30	Back of New Marina
4	60	Back of New Marina
Proposed Harbor Size (800 slips)		
5	0	None
6	15	None
7	30	None
8	60	None
Proposed Harbor Size (800 slips)		
9	0	Back of Existing Harbor
10	60	Back of Existing Harbor

Simulations in Table 5-2 were conducted with a 400 slip marina, variations in the exhibit flow outfall location, and variations in the amount of brackish groundwater that could be intercepted by the new Marina. The 400 slip marina represents a reduction in volume by half of the 800 slip marina. Note, that the purpose of reducing the size in the simulations was to reduce the volume volume of the marina and this was independent of the number of slips that the Marina will finally have. The goal of this large number of simulation is to asses under what future project conditions water quality conditions within the Harbors and along the coastline of the state Park could be optimized.

The model that was constructed and described in Section 3.3 was modified to represent a new Marina layout that would effectively reduce the original volume by approximately one half. The resulting model grid is shown in Figure 5-1. For simplicity, the bathymetry within the Marina was kept the same as previously described. The goal of the reduction was to lower the flushing time within the new and existing Marinas and remain as close as possible to the conditions that presently exist within Honokohau Harbor.

Hydrodynamic, flushing time, and water quality numerical models were implemented using the conditions described in Section 3.3. The tidal conditions for the water quality model were further constrained to only represent one representative tidal cycle repeated in order to increase computational efficiency for the large quantity of simulations that were considered. This repeated signal is shown in Figure 5-2. Note that the model is representative of typical conditions and therefore neglecting the spring/neap variability of the tidal signal should not influence the conclusions extracted from the comparison of alternatives. Furthermore, sensitivity tests were carried out to compare results between simulation with a repeated representative tidal cycle and with a complete spring/neap tidal signal. These tests indicated that simulated water quality conditions are mainly controlled by the different water inflows into the system (groundwater brackish water and exhibit flow) and that tidal variability only incorporates some variability into the parameters. Water quality simulations with the repeated representative tidal cycle were carried out until the conditions in the harbor have achieved a relative steady situation.

Table 5-2: Scenarios for 400 slip Marina

Proposed Harbor Size (400 slips)		
Simulation number	Quantity of Brackish Discharge	Location of Exhibit Discharge
11	0	Back of New Marina
12	10	Back of New Marina
13	20	Back of New Marina
14	30	Back of New Marina
15	60	Back of New Marina
Proposed Harbor Size (400 slips)		
16	0	None
17	10	None
18	20	None
19	30	None
20	60	None
Proposed Harbor Size (400 slips)		
21	0	Back of Existing Marina
22	10	Back of Existing Marina
23	20	Back of Existing Marina
24	30	Back of Existing Marina
25	60	Back of Existing Marina

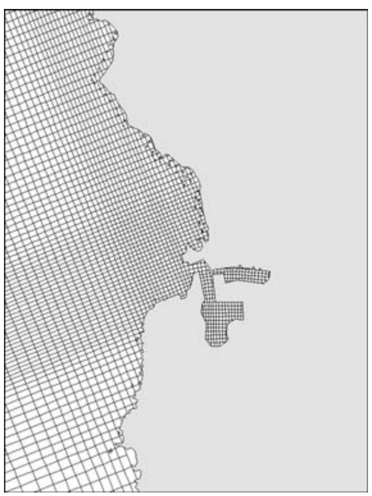

Figure 5-1: Adjusted grid for 400 slip Marina

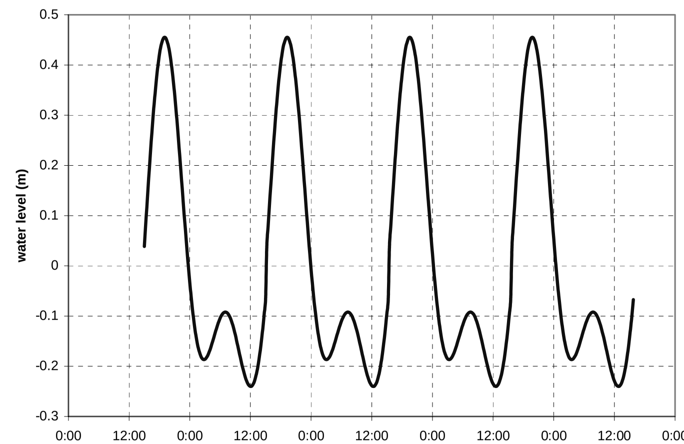

Figure 5-2: Repeated tidal cycle used for water quality simulations

5.3 Flushing Time

The major indicator of the water quality of a harbor is its flushing time. Ferreira et al. (2005) reported that flushing time is the most significant controller of eutrophication and biodiversity within a system. Flushing time results of the simulations using the 800 slips Marina of the Conceptual Master Plan described in Section 3.3 are also presented in Figure 5-3. Cases where the exhibit outfall discharges at the back of the new Marina were considered. In order to assess the effects of the discharge on the marinas, it was also excluded from the model in order to test the model's reaction to its inclusion. This condition could be representative of discharging the outfall offshore or eliminating the exhibits altogether. For the 800 slip marina, all cases showed a significant increase in flushing time from the current conditions. Flushing time increased in the existing Harbor from 12 hours to values up to 35 hours when no brackish groundwater inflow is considered in the new marina. At the new Marina flushing time could reach values up to 60 hours when neither brackish groundwater inflow nor exhibit flow is considered. Adding the exhibit flow into the existing marina proved to be effective in reducing the flushing time in the existing harbor from the aforementioned values particularly for the case of 60 mgd brackish groundwater inflow into the new Marina. The new Marina is not affected significantly by the change in pipe location. However, the values indicate that the situation still may not meet the water quality conditions that currently exist within Honokohau Harbor and indicate that water quality still may be impacted post-expansion.

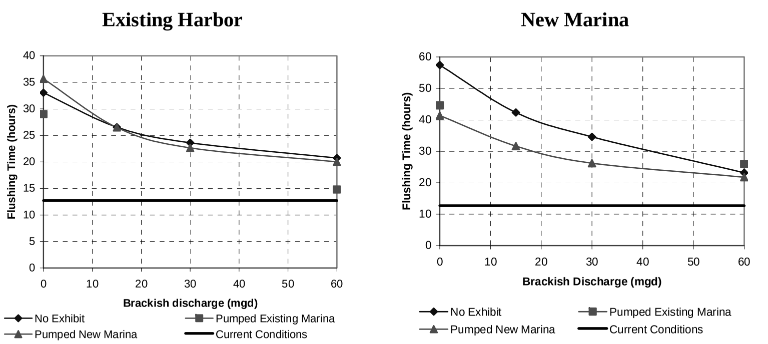

Figure 5-3: Flushing times of 800 slip marina

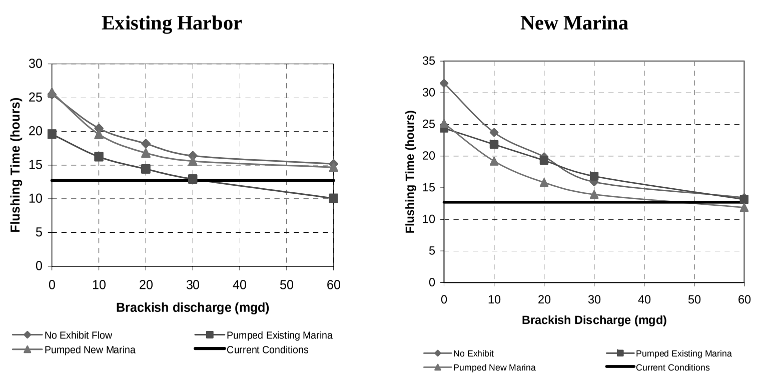

Figure 5-4: Flushing times of 400 slip Marina

In order to decrease the flushing time of the two-marina system, a reduction in the size of the proposed Marina was considered. Comparison of Figure 5-4 with Figure 5-3 shows that the reduction of the Marina size to 400 slips significantly affects the flushing times in both the existing and new Marinas for all the cases simulated. The influence is about five hours, which is significant when considering that the phytoplankton growth in a system with unlimited nutrients is exponential in time. In addition, pumping the exhibit discharge into Honokohau Harbor clearly reduces the flushing time in the Harbor significantly (> 5 hours: 25% improvement at Q=0 mgd and 50% improvement for Q=60 mgd), and pumping it into the new Marina also has an effect, but one that is less pronounced due to the size of the new Marina (2-3 hours). The flushing times under high brackish groundwater inflow conditions are comparable to the flushing

times under existing conditions, which may be sufficient to control algae growth within the new Marina. It should be noted that while the interception of brackish flow into the new Marina may help the water quality within the Harbor, it is also the source of inflow to the anchialine ponds west of the proposed new Marina and the quantity of water intercepted could impact the salinity of these ponds significantly, changing the ecology of these systems (Ziemann, 2006). Note also that the increase in brackish groundwater inflow to the Harbor system will increase the quantity of brackish water leaving the system at the harbor mouth, which could have impacts on the salinity of the surrounding areas. In particular, examining the salinity profiles obtained from the model simulations at station J (OI Consultants, 1991) shows that largest differences in salinity are observed at the surface; the differences are less than 1 ppt for the 60 mgd groundwater brackish inflow into the new Marina (Figure 5-5 through Figure 5-9). As brackish inflow increases into the Honokohau/Kona Kai Ola system, the layer at the surface outside of the Harbor becomes less dense. In addition, the position of the exhibit discharge influences the salinity at the surface outside of the harbor. When the exhibit discharge is positioned at the back of Honokohau Harbor the salinity in the surface layers is higher. The lowest salinity occurs when an exhibit discharge is not included at any location.

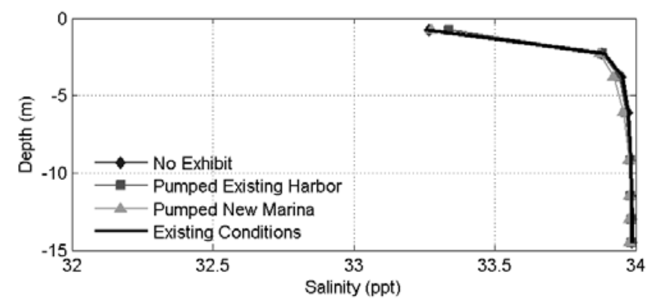

Figure 5-5: Salinity profile at station J (OI Consultants, 1991) for 0 mgd brackish inflow

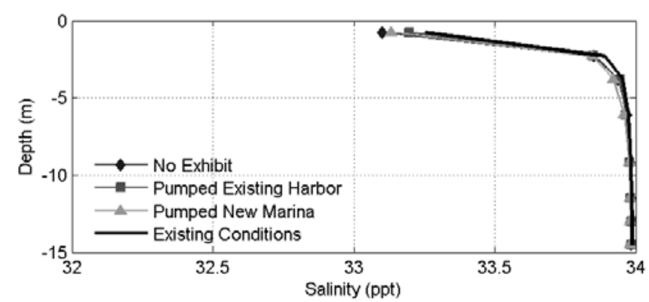

Figure 5-6: Salinity profile at station J (OI Consultants, 1991) for 10 mgd brackish inflow

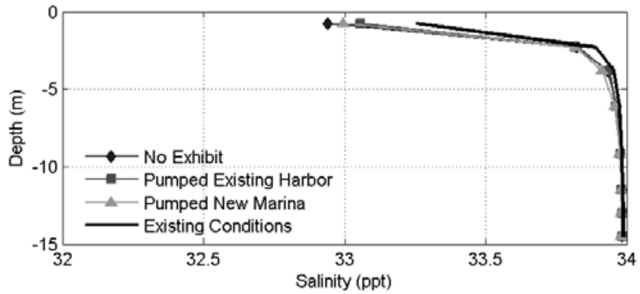

Figure 5-7: Salinity profile at station J (OI Consultants, 1991) for 20 mgd brackish inflow

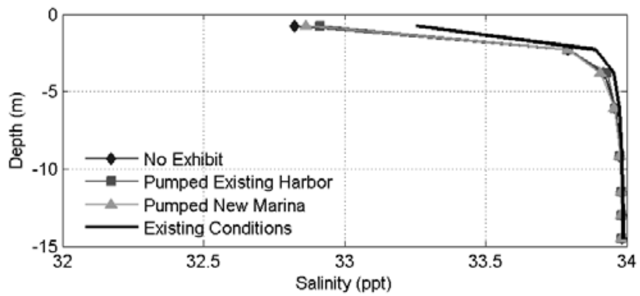

Figure 5-8: Salinity profile at station J (OI Consultants, 1991) for 30 mgd brackish inflow

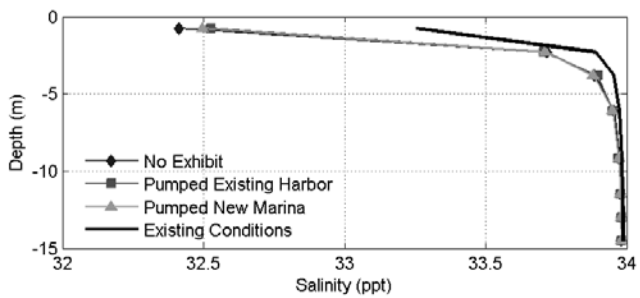

Figure 5-9: Salinity profile at station J (OI Consultants, 1991) for 60 mgd brackish inflow

5.4 Nutrients

Nutrient loads into the proposed new Marina are extremely dependent on the brackish water inflow. Since this quantity is unknown but has been bracketed into "reasonable" values for these simulations, it is difficult to determine exactly what the final nutrient profile will be within the proposed system. Because present conditions within Honokohau Harbor will be affected by the construction of the new Marina, it is beneficial to examine these effects in a broad manner. The two conditions that are available for comparison are the present conditions within Honokohau Harbor and the guidelines set by the state of Hawaii for water quality in the region. The following sections will describe the standards and classifications set, the future conditions that are typically expected within the Marina systems and the typical conditions that are expected immediately outside the Harbor mouth. Nutrient concentrations along the coastline of the Kaloko-Honokohau National Historical Park will be examined in a later section for selected scenarios.

5.4.1 Hawaii State Standards

Water quality standards for the state of Hawaii are described in Chapter 54 of the Hawaii revised statues (Department of Health, 2004). Water quality standards for the state of Hawaii designate Honokohau Harbor as Class A recreational area. The waters surrounding Honokohau Harbor are designated as Class AA pristine waters with stricter standards. It is therefore necessary to determine whether the existing Harbor is currently meeting the water quality standards and to determine whether the new Marina will create worse conditions with respect to standards in the area. Table 5-3 presents the Hawaii water quality standards; the values reported are geometric means for wet conditions. This assumes that additional, non-tidal inflow to the Harbor consists of greater than 1% of the total volume of the Harbor, which is the specification for Class A waters. The State also mandates exceedance criteria for the areas; however due to the assumption of typical conditions for the model, these criteria cannot be analyzed.

Table 5-3: Hawaii water quality standards

	Class A	**Class AA**
Ammonia-nitrogen (NH_4-N)	6 µg-N/L	3.5 µg-N/L
Nitrate-nitrogen (NO_3-N)	8 µg-N/L	5 µg-N/L
Total Phosphorous (PO_4-P)	25 µg-P/L	20 µg-P/L
Chlorophyll a (CHLa)	1.5 µg-Chla/L	0.3 µg-Chla/L

5.4.2 Nutrients within Honokohau Harbor and Kona Kai Ola Marina

For the purposes of this brief analysis of alternative performance, it was necessary to develop a mean value that represents the Harbors rather than describing the spatial and temporal variability. The spatial attributes of a select number of cases are described at length in a later section. For these purposes, all values were tidally averaged over the representative period after the model reaches a quasi-steady state solution and were then averaged over depth and space for both the Honokohau Harbor and Kona Kai Ola Marina. These areas are delineated in Figure 5-10. In this figure, the overlapping region between Kona Kai Ola Marina and Honokohau Harbor near the Harbor entrance is spatially averaged into both regions.

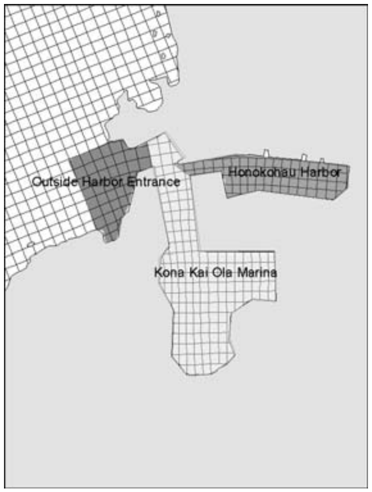

Figure 5-10: Locations of spatial averaging

These values do not represent variability related to seasonal tidal cycles or any seasonal effects. They are merely used as a gauge for measuring the changes in water quality associated to the different simulated scenarios.

Nitrate-nitrogen (NO_3-N)

The average nitrate-nitrogen values within Honokohau Harbor and the 400 slip Kona Kai Ola Marina are shown in Figure 5-11. It can be seen that even under existing conditions, the NO_3-N concentrations are not within the Hawaii standards for Class A waters. The 400 slip harbor shows NO_3-N concentrations increasing in a nearly linear trend as the quantity of brackish groundwater increases. Levels in the existing Harbor are highest for the cases where the exhibit water is pumped into the existing Harbor since this water is high in NH_4-N which is then nitrified into nitrate. In addition, the shorter flushing time that occurs in the Harbor with the added exhibit flows does not allow for as much algae growth and nutrient utilization, leaving the water column concentrations higher than in the other scenarios. The nitrate levels within the new Marina tend to be lower than the levels in the existing Harbor. This is due to the fact that the volume of the new Marina is larger than that of the existing Harbor which dilutes the nutrient concentrations in brackish groundwater inflows.

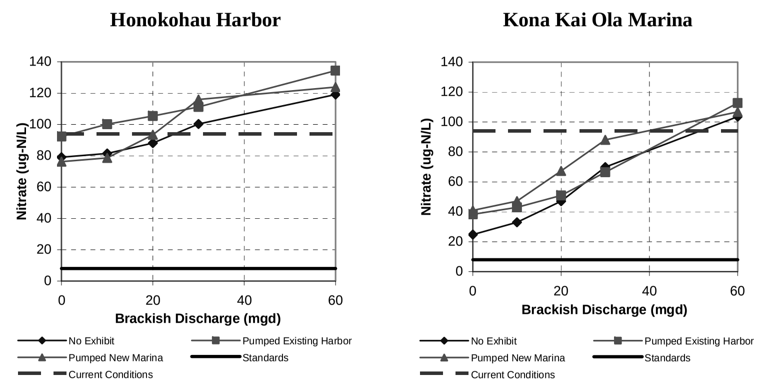

Figure 5-11: Nitrate-nitrogen (NO_3-N) conditions within Honokohau Harbor and 400 slip Kona Kai Ola Marina

Ortho-Phosphate(o-P)

Ortho-phosphate concentrations for Honokohau Harbor and the 400 slip Kona Kai Ola Marina are shown in Figure 5-12. These concentrations show a near linear trend similar to the concentrations of NO_3-N within the two harbors. Existing conditions show concentrations within the Hawaii standards for Class A waters. The proposed Marina does not increase the levels significantly for existing conditions and even in low brackish groundwater conditions, it results in a lowering of the ortho-phosphate concentrations.

Ammonia-nitrogen (NH_4-N)

NH_4-N values within the existing and new Marinas are shown in Figure 5-13. It is obvious that pumping the exhibit discharge with high NH_4-N concentrations into the existing Harbor significantly affects the ammonium concentrations in the existing harbor, exceeding the Hawaii state standards by almost 10 µg-N/L. This effect is also present in the new Marina when the exhibit flow is pumped into the back wall. The ammonia concentrations increase by about 6 µg-N/L also driving them above Hawaii state standards, although the effect is not as pronounced as that which occurs within Honokohau Harbor mainly because the larger volume of Kona Kai Ola Marina dilutes the concentrations to lower values within the new Marina.

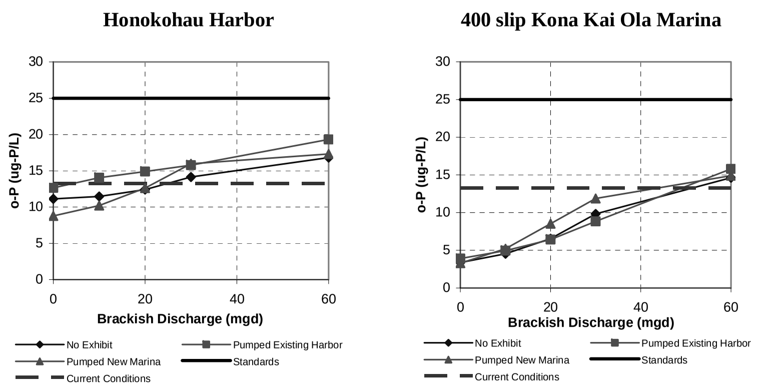

Figure 5-12: Ortho-phosphate (o-P) concentrations within Honokohau Harbor and 400 slip Kona Kai Ola Marina

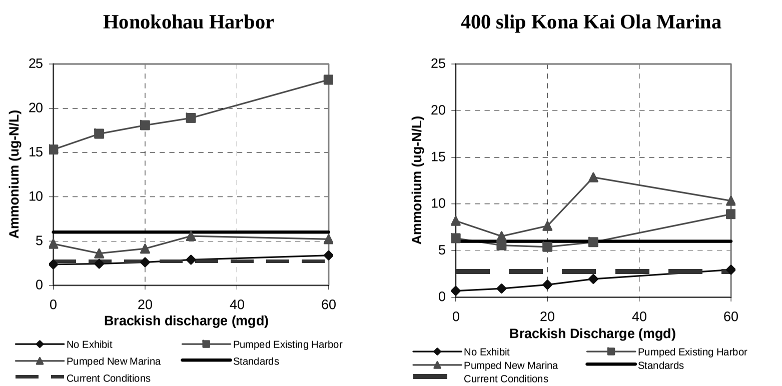

Figure 5-13: Ammonium-nitrogen (NH_4-N) concentration within Honokohau Harbor and 400 slip Kona Kai Ola Marina

<u>*Chlorophyll a (CHLa)*</u>

The Chlorophyll a values within the existing and new Marinas were computed based on the kinetic and physical dynamics of the system. It was found that decreasing the size of the new Marina was beneficial in controlling the excessive algae growth that was found to be problematic under the proposed 800 slip Marina. Under the groundwater inflow ranges modeled, it is found

that the smaller new Marina remains below approximately 3 µg-chla/L for all solutions (Figure 5-14). This indicates that both Marinas will exist in an oligotrophic state under typical conditions. In order to reach the Hawaii Class A standards that are set for Honokohau Harbor, a number of different scenarios were tested. It was found that with high levels of brackish water inflow, the harbors are more likely to be close to or below the Class A standards. The algae growth within the existing Harbor is severely limited when the exhibit flow is pumped into the back of this harbor. This indicates that this would be the best scenario to maintain the water quality within Honokohau Harbor. Pumping the exhibit flow into the back of the new Marina also benefits the existing Harbor, but the effect is not enough to lower Chlorophyll a concentrations to existing levels. With the cases corresponding to the mid-inflow values (20-30 mgd, which is similar to the inflow into the existing Harbor), brackish groundwater inflows into the new Marina show a significant decrease of Chlorophyll a concentrations at the Marina where the exhibit water is discharged.

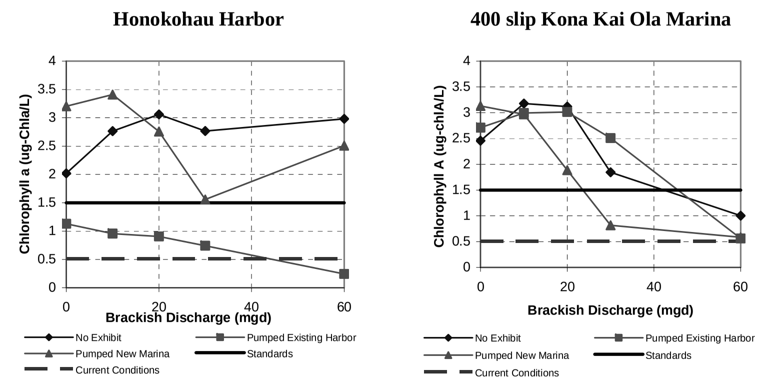

Figure 5-14: Chlorophyll a concentrations within Honokohau Harbor and 400 slip Kona Kai Ola Marina

It can be seen from the above analysis that simulations when the brackish groundwater flow into the new Marina are in the order or greater than 30 mgd, provide conditions that are approaching or within water quality standards for Class A waters. In addition flushing under these conditions appear to control the eutrophying potential of the high nutrient loads coming in from the brackish groundwater. These brackish groundwater inflow conditions seems to be possible based on the expert opinion of Waimea Water Services (2007) who states that it is likely that the construction of Kona Kai Ola Marina will likely intercept significant brackish groundwater post-expansion. In addition, it is expected that if the inflow of brackish groundwater is even higher than was tested, the flushing will be even more pronounced and the water quality conditions could be even better.

Another important observation is the influence of the exhibit water entering the marina. The exhibit water does not seem to affect the growth of algae except in its relationship to the flushing of the Harbor and Marina. Due to the nutrient limitations discussed in the following section, the additional nitrogen load does not cause additional algae growth, however it does cause increased ammonia and nitrate loads. It is expected that if this load is reduced, the exhibit inflow will have a beneficial additional flushing effect and at the same time it will not affect algae growth.

Nutrient Limitation

The limiting nutrient within the new and current system was found to be ortho-phosphate. This was tested in two ways. Among all the simulated cases, there are scenarios that contain "extra" nitrogen from the exhibit flow without additional phosphorous concentration. If the system were to be nitrogen limiting, this addition of available nitrogen to the system would cause additional algae growth. However, as is seen in the above section, the Chlorophyll a production with the addition of the exhibit flow is minimal at best. In addition, in other sensitivity tests, the phosphorous concentration in the brackish inflow was increased arbitrarily by a factor of two to determine if this would cause additional algae growth. In fact, the chlorophyll production increased significantly with the addition of extra ortho-phosphate, which corroborates the phosphorous limitation discussed in Section 4.8.1.

This determination is important as it signifies the impact of additional phosphorous loads on the system and the need to monitor those loads extremely carefully to maintain the water quality within the system.

5.4.3 Nutrients immediately outside Harbor Entrance

The area immediately surrounding the harbor mouth is examined in OI Consultants (1991). This area was examined for all the simulated cases in order to determine the effect that the new Harbor system has on the water quality conditions at the immediate surrounding waters. This area is also shown in Figure 5-10. Similarly to the analysis performed for Honokohau Harbor and Kona Kai Ola Marina, the model results at the selected location outside of the Harbor entrance were tidally averaged over the representative period after the model spin-up period and were then averaged over depth.

Nitrate-nitrogen (NO_3-N)

The average nitrate-nitrogen values outside of the Harbor entrance are shown in Figure 5-15. It can be seen that even under existing conditions, the nitrate-nitrogen levels exceed the Hawaii standards for Class AA waters. Nitrate levels increase in a nearly linear trend with the groundwater brackish inflow into the new Marina. Nitrate concentrations are higher when the exhibit water is pumped into the Marina system since this water is high in ammonia which is then nitrified into nitrate. In general, nitrate concentrations after the new Marina construction are expected to be in the same order to those observed under existing conditions.

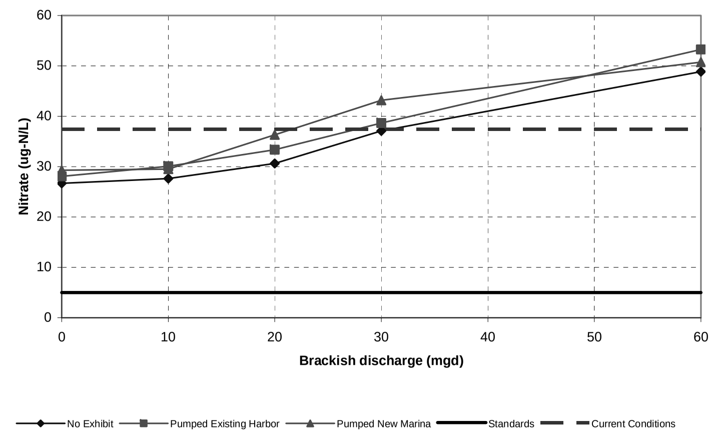

Figure 5-15: Nitrate-nitrogen concentrations outside Harbor entrance

Ortho-Phosphate (o-P)

Ortho-phosphate levels outside of the harbor entrance are shown in Figure 5-16. These concentrations show a near linear trend similar to the values of nitrate outside of the Harbor entrance. Existing conditions show concentrations within the Hawaii standards for Class AA waters. The proposed Marina does not increase the levels significantly from existing conditions and even in low groundwater brackish inflow, it results in a lowering of the ortho-phosphate levels.

Ammonium-nitrogen (NH_4-N)

NH_4-N levels outside of the Harbor are shown in Figure 5-17. This shows that NH_4-N concentrations are noticeably increased by including the exhibit flow, however still meet the Hawaii state standards. The influence of the exhibit flow is most pronounced outside of the harbor when it is pumped into the existing Harbor.

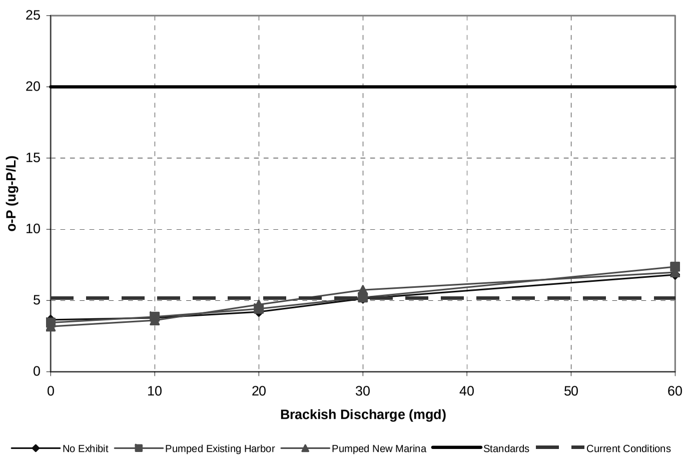

Figure 5-16: Ortho-phosphate conditions outside Harbor entrance

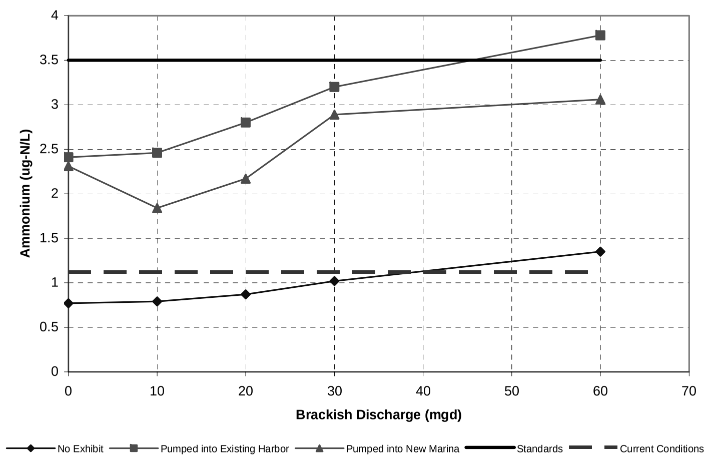

Figure 5-17: Ammonium conditions outside of the Harbor entrance

Chlorophyll a

Immediately outside the Harbor entrance, the Chlorophyll a values are mainly confined to the surface layers of the system for all scenarios. Figure 5-18 shows the tidally and depth averaged values for the area just outside of the Harbor. These values appear to consistently exceed Class AA standards shown in Table 5-3; however they all fall below the standards for Class A waters (Table 5-3). Due to the area's proximity to the Harbor entrance, this may still remain acceptable as long as the algae dies and is diluted within a reasonable distance from the Harbor mouth. This is examined in more detail in Section 6.

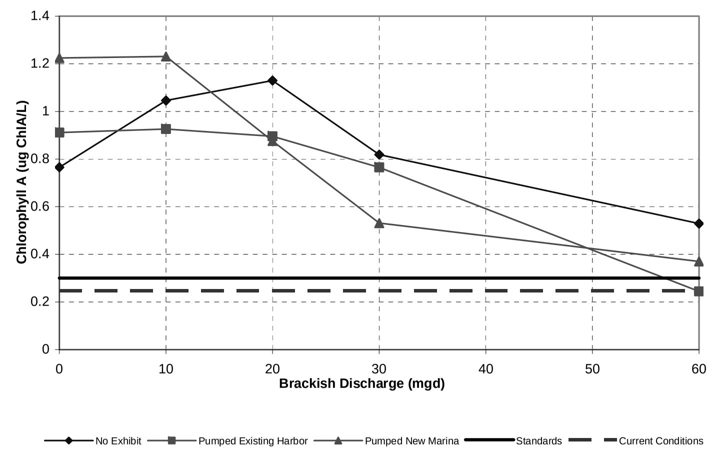

Figure 5-18: Chlorophyll a values outside the Harbor entrance

5.5 Detailed Description of Two Alternatives

From all the simulated alternatives, two were selected for further discussion. In order to select these two cases, the following conclusions from the model results were considered:

- While the cases pumping the exhibit flow into the existing Marina provided overall better water quality results, it may be considered not advantageous to further impact the conditions of Honokohau Harbor.
- Since the addition of the large quantity of water from the exhibits does have slightly beneficial results in terms of flushing time and the excess nitrogen does not affect the water quality due to the phosphorous limitation, cases including the exhibit flow in the new Marina were selected.
- Since the brackish water inflow is an unknown quantity, one reasonable assumption is that the same amount of water that is intercepted by the existing Harbor could also be intercepted by the new Marina. Therefore, the 30 mgd case was selected as the most reasonable case with beneficial results.

- In addition, the case containing 0 mgd of brackish groundwater is also analyzed as a bounding case, since this condition appears to cause some of the worst algae production. It is worth noting that although the case with 0 mgd of brackish inflow does allow significant algae growth, all the cases analyzed with a 400 slip marina create oligotrophic conditions in both new and existing Marinas, while some cases analyzed with the 800 slip marina led to eutrophic conditions.

5.5.1 *Case 1: 400 slip New Marina, 0 mgd brackish groundwater inflow, exhibit flow pumped into new Marina*

Currents

The velocity structure under this alternative that is without brackish groundwater into the new Marina is similar to the conditions observed with the 800 slip Harbor. Density currents are not generated within the new Marina due to the lack of brackish groundwater inflow. Therefore, internal circulation between the two harbors remains problematic as in the 800 slip case. The new Marina still shows a top layer moving towards the back of the new Marina from the existing Harbor (Figure 5-19) and a bottom layer moving out towards the ocean. The back end of the new Marina is defined at 0 m. This internal circulation prevents the two-layer "pumping" observed under existing conditions in Honokohau Harbor. It therefore increases the flushing time, which is 25 hours in this scenario, and leads to build up and growth of algae within the system.

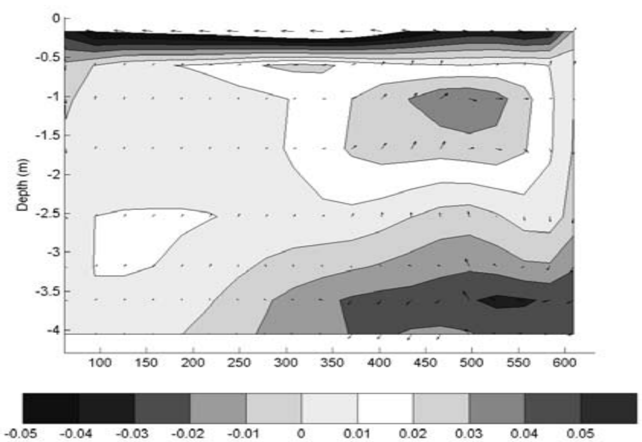

Figure 5-19: Velocities at peak flood (m/s) along Transect NM (Figure 3-12) for Case 1

At the Harbor mouth the depth distribution of velocities is similar to those shown in Sections 3.2.6 and 3.3.5. The profiles shown in Figure 5-20 are at the location specified in Figure 3-12. It is seen that during ebb tide for this scenario, there is no water entering from the ocean at the bottom layer, which could also impact the amount of flushing that is occurring.

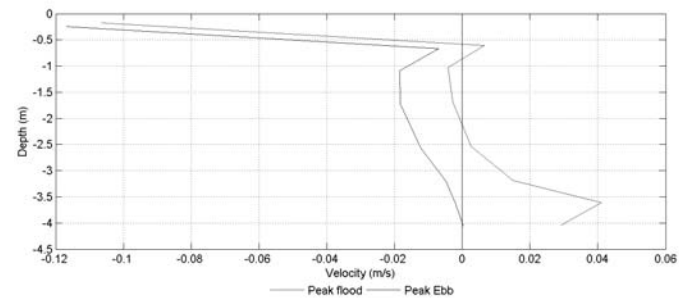

Figure 5-20: Velocity profiles at harbor entrance (Figure 3-12) for a brackish inflow of 0 mgd and a 400 slip new Marina

Salinity

The salinity patterns within the existing Harbor retain a similar structure to those found under existing conditions, as there are not any density changes in the new Marina to affect the structure in the existing Harbor (Figure 5-21 and Figure 5-21). However, in the surface layers towards the ocean side of the Harbor, the water is slightly more saline due to the fact that the low salinity water is entering the new Marina and is not all continuing out in the surface layers to the ocean.

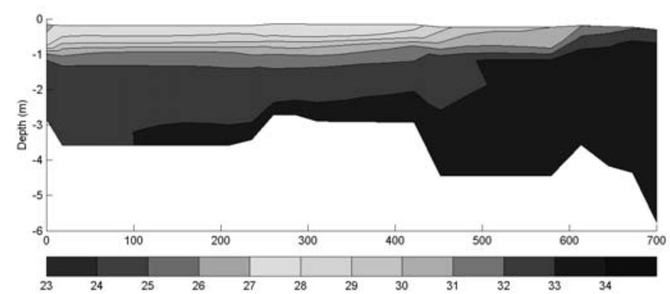

Figure 5-21: Salinity at peak flood (ppt) along Transect EH (Figure 3-12) at high tide for Case 1

The salinity contours within the new Marina show that the main body of water within the new Marina is highly saline (Figure 5-22). Only a small amount of brackish water found at the surface near the intersection of the two harbors is present. This brackish water is moving toward the back of the new Marina as shown in the previous section.

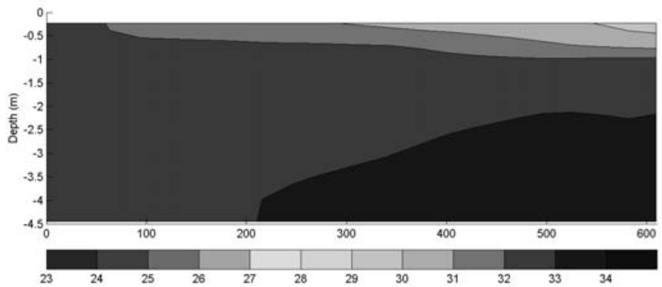

Figure 5-22: Salinity contours at peak flood (ppt) along Transect NM (Figure 3-12) for Case 1

Chlorophyll a

Chlorophyll a concentrations within the existing Harbor at high tide are shown in Figure 5-23. These values are fairly high at the back of the existing harbor. They retain the same depth trend as is shown under existing conditions. The chlorophyll a concentrations within the Harbor range from 2 to 5 µg-Chla/L. The mean value that was reported in Section 5.4.2 was 3 µg-Chla/L; however, spatial and depth variability is great. Under existing conditions, the high value was about 0.5 µg-Chla/L.; thus, the degradation of the water quality under these conditions is apparent even with the smaller proposed 400 slip Marina.

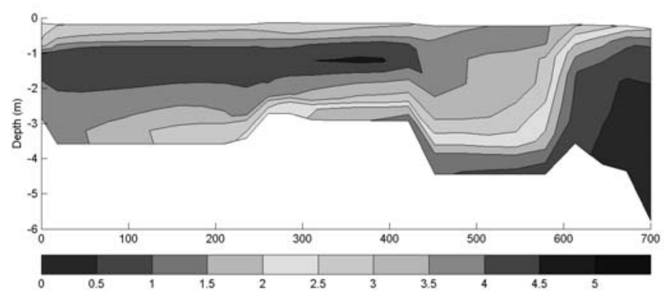

Figure 5-23: Chlorophyll a concentrations at peak flood along Transect EH (Figure 3-12) for Case 1

Within the new Marina, Chlorophyll a concentrations are high in the surface layers toward the middle of the new Marina (Figure 5-30). The nutrients for the algae consumption and reproduction enter the new Marina at the surface layer (coming from the existing Harbor). The algae resist growing near the intersection of the two harbors because the water at the surface is brackish and the more saline environment near the middle of the Marina is favored. Near the back wall, the discharge from the exhibit contains minimal Chlorophyll a concentrations; therefore this area near the wall does not promote as much algae growth.

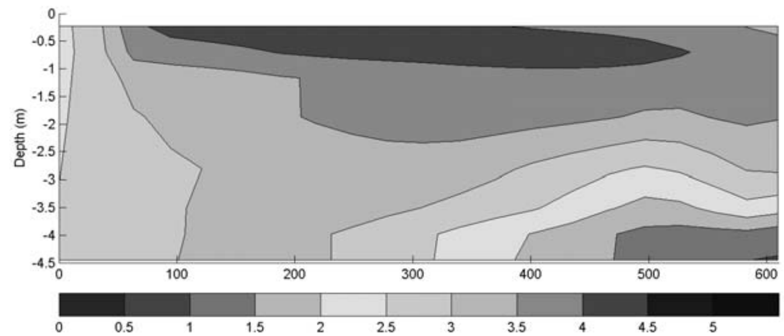

Figure 5-24: Chlorophyll a concentrations at peak flood (µg-chla/L) along Transect NM (Figure 3-12) for Case 1

5.5.2 Case 2: 400 slip new Marina, 30 mgd brackish groundwater inflow, exhibit flow pumped into new Marina.

Currents

The velocity structure with 30 mgd of brackish groundwater flowing into the new Marina develops into more defined (relative to Case 1) two layer structure and exhibits much higher velocities flowing out of the new Marina than were observed in Case 1 (Figure 5-25). This indicates that the new Marina is developing a density current system similar to what is observed under existing conditions in Honokohau Harbor. This is also observed in the flushing time of the new Marina which is shown to have decreased to about 13 hours from the 25 hours observed in Case 1. This is an indicator that overall water quality will be significantly improved within the new Marina, as it is starting to draw in ocean water at higher velocities and push out water in the middle layers at faster velocities.

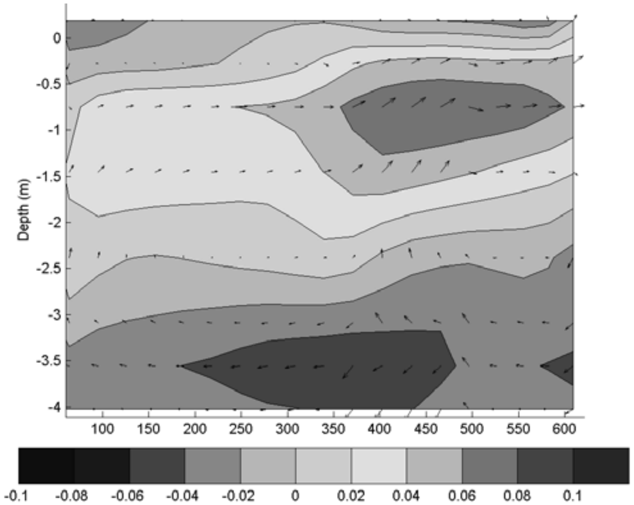

Figure 5-25: Velocities at peak flood (m/s) along Transect NM (Figure 3-12) for Case 2

At the harbor entrance, the velocity profiles at peak flood and peak ebb look similar to those shown in Sections 3.2.6 and 3.3.5; however it should be noted that there is a recurrent inflection in the velocity profiles that is directed out of the Harbor at about 1 to 2 m of depth (Figure 5-26). This is due to the flow that exits the new Marina below the surface layer. This layer also appears to always be directed out of the Harbor during both flood and ebb tide. During peak ebb, there is still flow entering the Harbor system at the bottom layer; however the velocities are not as high as those under existing conditions. This among other factors may contribute to the degradation of the water quality within the existing Harbor.

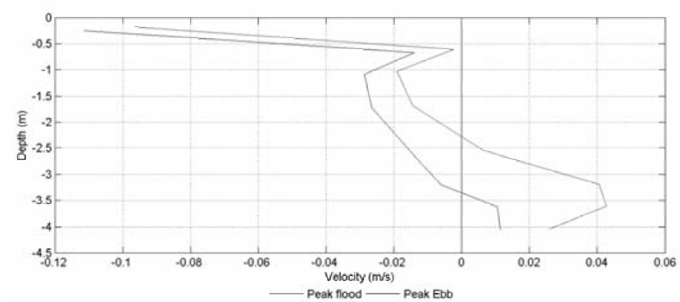

Figure 5-26: Velocity profiles at harbor entrance for a brackish inflow of 0 mgd and a 400 slip new Marina

<u>Salinity</u>

The salinity profiles within the existing Harbor appear similar to those shown in Figure 3-18. It is of note that the salinity in the back end of the existing Harbor is slightly more brackish (Figure 5-27), and that the contours extend further down in the water column. This is of note because it indicates that the nutrient-laden brackish water that under existing conditions is confined to the surface water is mixed into the lower layers, creating a more suitable environment for algae growth.

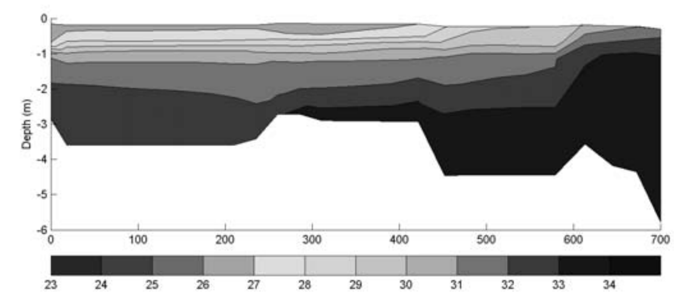

Figure 5-27: Salinity at peak flood (ppt) along Transect EH (Figure 3-12) at high tide for 0 mgd brackish water inflow and 400 slip new Marina

Salinity within the new Marina is much more stratified than in Case 1. This induces more density driven flows into and out of the new Marina.

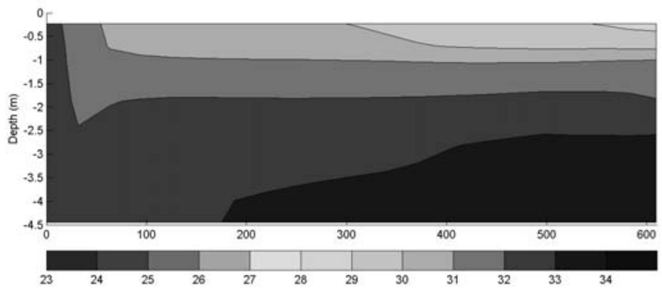

Figure 5-28: Salinity contours at peak flood (ppt) along Transect NM (Figure 3-12) for Case 2.

Chlorophyll a

Within the existing Harbor, there is a wide range of Chlorophyll a concentrations. While the value reported as the mean value for the entire Harbor was 1.5 µg-chla/L, it is seen in Figure 5-29 that the values within the existing Harbor range from almost zero to almost 4 µg-chla/L. However, it is also noted that this range is much more variable and tends to be lower than that found in Case 1. This indicates that more of the nutrients and algae are moved out of the system. It still appears that not enough ocean water is pumped through the system. This is evidenced by the lower salinities in the deeper parts of the back basin. More nutrients are remaining in the system, and the algae growth in the back of the existing Harbor is higher than in the rest of the system. It was also shown in previous sections that pumping the saline exhibit water into the existing Harbor also significantly increases the mixing within this Harbor.

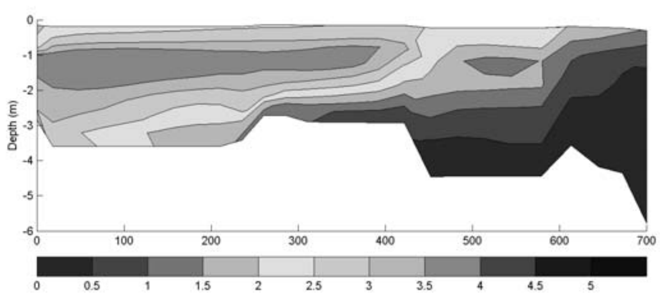

Figure 5-29: Chlorophyll a concentrations at peak flood (µg-chla/L) along Transect EH (Figure 3-12) for Case 2.

Chlorophyll a concentrations within the new Marina are very low, with only slightly higher concentrations near the intersection of the existing Harbor (Figure 5-30). This indicates that 30 mgd of brackish water appears to be significant enough to flush this marina adequately enough to prevent significant algae growth. It also indicates that the new Marina may be intercepting more ocean water that is drawn into the existing harbor under existing conditions.

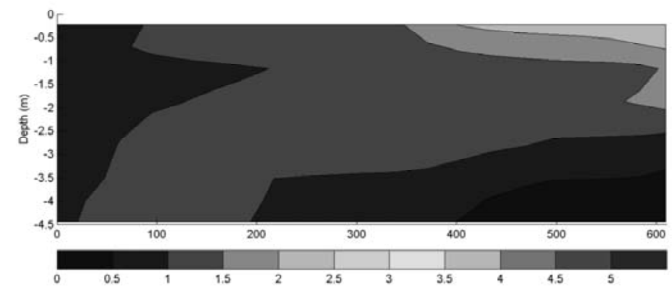

Figure 5-30 Chlorophyll a concentrations at peak flood (µg-chla/L) along Transect NM (Figure 3-12) for 0 mgd brackish water in 400 slip Marina

6. EFFECT ON SURROUNDING COASTLINE

The hydrodynamic and water quality model described in Chapters 3 and 4 was developed and calibrated to reproduce existing conditions in the Honokohau Harbor and future conditions in the new Marina system. Although the model reproduces the velocities and water level variation under tidal conditions at Honokohau Bay, it has not been calibrated to reproduce accurately the salinity distribution or water quality in that area. Water quality model calibration at Honokohau Bay was not considered part of this study mainly due to the scarcity of oceanographic and water quality data and most importantly the unavailability of data regarding groundwater brackish water inflows into the ponds and through the coastline and anchialine ponds. In order to calibrate the water quality model including Honokohau Bay, a comprehensive data collection effort together with a thorough groundwater study would be necessary.

Because the coastal area north of Honokohau Harbor (Honokohau Bay) is important due to its coral populations as well as its proximity to Kaloko-Honokohau National Historical Park and its existing pristine natural state under the state's Class AA designation, the numerical model has been used to estimate possible changes from existing water quality conditions in Honokohau Bay due to the development. The nutrient concentrations in this region are important to the National Park Service and it is necessary that nutrient concentrations within the region conform to state standards for the Class AA pristine climate that exists currently. Note that results presented in this section should be used with caution. They provide an approximate measure of relative changes in water quality conditions caused by the new marina development.

Due to the previously explained limitations in model predictability, the effect of the new development in the water quality of the surrounding coastal areas cannot be estimated in absolute terms from the simulations, as the water quality model was not calibrated for these areas. As it was already mentioned, determining the quantity and quality of the groundwater discharged at specific locations along this coastline was beyond the scope of the study, and while coastal groundwater brackish inflows along the coastline were included, their amounts and also nutrient concentrations were approximated and not directly observed. Therefore, the changes that occur at neighboring areas of Honokohau Bay due to the introduction of the proposed Kona Kai Ola Marina are represented as relative changes from the existing conditions. For all sections and comparisons, plots are provided showing the relative difference (termed *Diff*) in concentration from existing conditions, be it a negative or positive difference. This was calculated using the tidally average mean value of the concentration, C_a, such that,

$$Diff = \left(C_{avNEW} - C_{avEXIST}\right)/C_{avEXIST}$$

The scenarios tested were compared in the previous section in the area just outside of the Harbor entrance to examine how the nutrients are diluted in this region. Both surface changes and bottom changes are shown in order to demonstrate the stratification of the system and the effects on the benthic and coral populations. Due to the fact that the large 800-slip marina results in significant water quality degradation, the analysis of the offshore effects is neglected for this alternative.

6.1 Depth Averaged Velocity

Bilger and Atkinson (1995) state that the nutrient uptake rate of a coral reef population is related to the velocity near the bed. Therefore, examining the impact of the proposed marina on velocities through the entrance channel of the Harbor is necessary.

In order to examine the effects of the proposed Marina on the nutrient uptake rate, the relative increase in velocities in the offshore region of coral populations were analyzed. The existing depth averaged velocity magnitudes in this region are shown in Figure 6-1. The changes associated to the additional marina are three-fold. First, there is an increase in tidal prism due to the expanded volume, which increases the flow through the Harbor entrance. Second, there is an unknown quantity of additional brackish groundwater that will be intercepted by the new Marina. Third, there is the potential of exhibit water discharge in the system. All of these effects serve to increase velocities through the entrance channel; however the simulated velocities remain relatively small

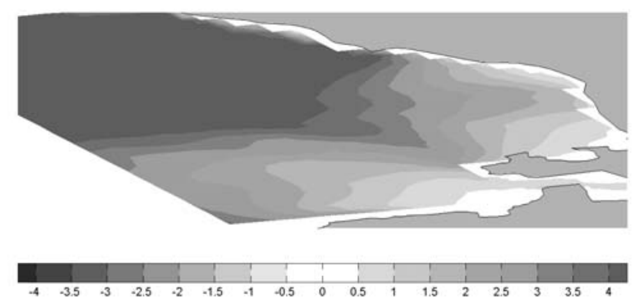

Figure 6-1: Depth averaged velocities (cm/s) under existing conditions

The increases are shown in Figure 6-2 for cases with exhibit flow included. It is shown that increases in depth averaged velocities are most pronounced in the Harbor mouth and dissipate quickly after exiting the Harbor. The figures in this section are based on relative differences. The numbers shown are meant to indicate fractional increase or decrease. The increase in velocity when including the exhibit flow is about 1.6 times the amount of the existing flow, so there is about a 1.6 cm/s increase in depth-averaged velocity through the entrance channel. This includes only the effects of the increased tidal prism and the additional exhibit water. When additional brackish inflow is accounted for, the depth-averaged velocities continue to increase by about 3 times the existing velocity, or 3 cm/s. This would result in depth-averaged velocities of about 4 cm/s through the entrance channel. It is noted that these velocities are influenced only by tidal and discharge effects. Velocity effects due to waves and oceanic currents could be fairly significant especially during seasonal events, in which case, the change due to the additional discharges and tidal prism would be less significant.

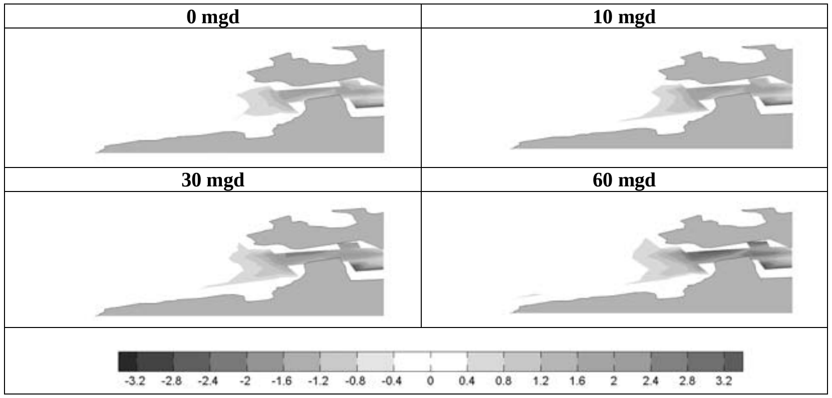

Figure 6-2: Relative increases in depth averaged velocity with exhibit water included

This increase in velocities is somewhat limited when the exhibit discharge is excluded (Figure 6-3); however the increased tidal prism and the additional brackish inflow continue to affect the velocities. In the case where there is not any additional brackish inflow and not any exhibit inflow, the increased tidal prism is the only factor affecting the velocities, and it appears that this effect alone causes an increase in depth-averaged velocity of about 0.8 to 1.2 cm/s (about 1x existing conditions higher velocities). However, it appears that when the exhibit water is excluded the effects on the depth-averaged velocities are more confined to the entrance channel and do not extend far from the Harbor mouth. This is likely to be important as it will control the surface area of coral that may be affected by the increased velocities.

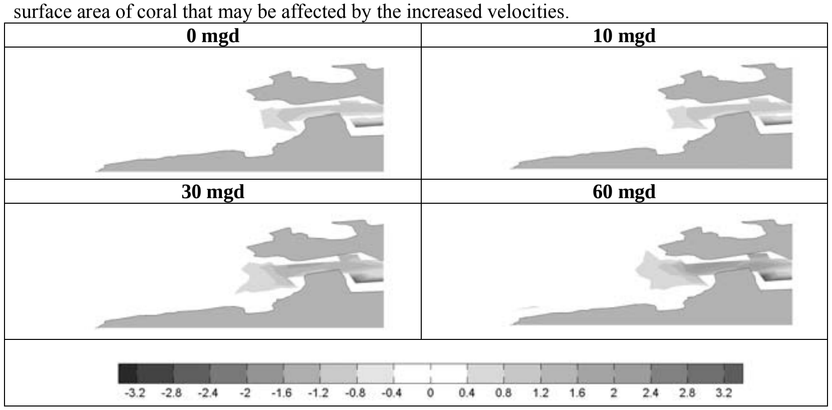

Figure 6-3: Relative differences in depth averaged velocity with exhibit water excluded

It is not possible to extrapolate exactly how the nutrient uptake rates in the area will be affected by the increased velocities. Bilger and Atkinson (1995) conducted their experiments in an extremely controlled environment, and they were more concerned with higher velocity flow (with tests starting at a minimum depth-averaged flow of 4 cm/s). This effect would have to be studied in more detail to get an accurate picture of the velocity effect on the coral in the area.

6.2 Salinity

The salinity of the waters outside of the Harbor changes by a very small amount both when the exhibit water is included in the model and when it is excluded. Figure 6-4 shows that for the cases with exhibit water included, the salinity at the surface exhibits changes that are very small when the amount of brackish groundwater entering the new Marina is small (<20 mgd). In the cases of 30 mgd and 60 mgd of brackish groundwater inflow, the system tends to become slightly fresher with almost a 4% decrease in salinity in the 60 mgd case.

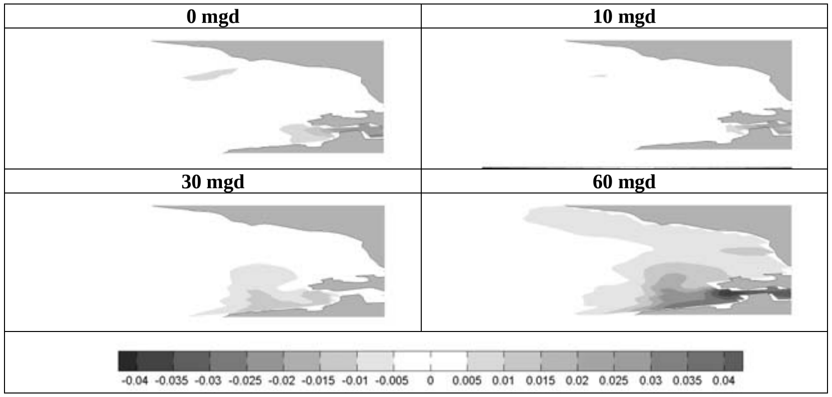

Figure 6-4: Relative salinity changes from existing (fraction) at the surface with exhibit flow included

Changes near the bottom outside the Harbor are even smaller, with maximum change being a reduction of about 1% along the shallow area of the Park coast at 60 mgd of brackish inflow. This indicates that the changes in salinity due to the brackish inflow are mainly confined to the surface layers, and that in the deeper waters away from the coast, the changes are extremely minimal near the bottom. This indicates that salinity conditions for the coral populations outside the harbor should remain similar to existing conditions post-expansion.

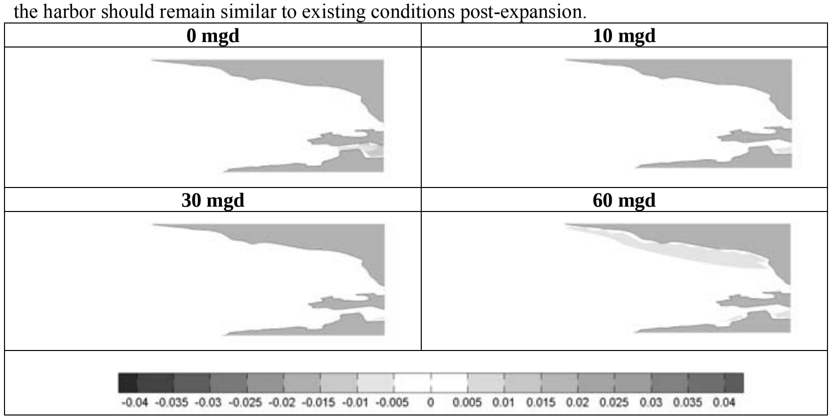

Figure 6-5: Relative salinity changes from existing (fraction) at the bottom with exhibit flow included

When the exhibit waters are excluded, the waters surrounding the Harbor show slightly more change than when the saline exhibit waters are included (Figure 6-6).

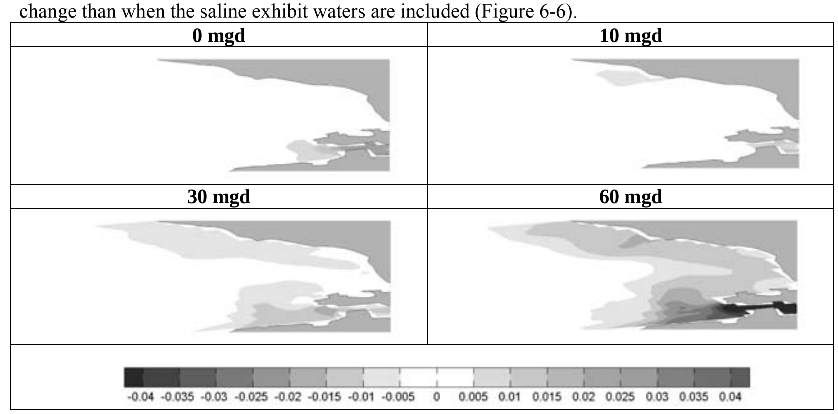

Figure 6-6: Relative salinity changes from existing (fraction) at the surface with exhibit flow excluded

For brevity, relative changes in salinity at the bottom with exhibit flow excluded are not displayed. Changes are within 0.005 ppt of existing conditions for all cases, indicating that changes in salinity are insignificant in the bottom layers without the exhibit inflow.

6.3 Nutrients

6.3.1 Nitrate-nitrogen

All nutrients (NO_3-N, o-P, and NH_4-N) follow similar trends in their exit from Honokohau Harbor; however, the levels of nitrate are most concerning, as the current conditions already exceed standards both within Honokohau Harbor and outside the Harbor. Figure 6-7 shows the relative additions to the nitrate-nitrogen concentrations in the vicinity of the Harbor when the exhibit outfall into the system is included. It shows that in the conditions with less brackish groundwater inflow, the concentrations in the vicinity of the National Park are less than current conditions. For the case with 30 mgd of additional brackish inflow, the concentrations are about 10 to 20 percent greater With 60 mgd, the concentrations can increase to 40 percent greater than current conditions. According to values reported by Ziemann in the area, nitrate-nitrogen concentrations range from about 300-900 µg-N/L at the surface. Therefore these increases of 10% are fairly small (<10 µg-N/L). It is worth noting that state standards mandate that Class A waters maintain a mean concentration of 8 µg-N/L.

Bottom concentrations follow similar trends (Figure 6-8) as the surface concentrations with concentrations decreasing with lower groundwater inflow, and increasing with higher groundwater inflow. The higher increases and decreases in concentration tend to be near the coastline of Kaloko-Honokohau National Historical Park. This is likely due to the shallow waters there which allow for nutrients confined to the surface layers mix into the bottom layers.

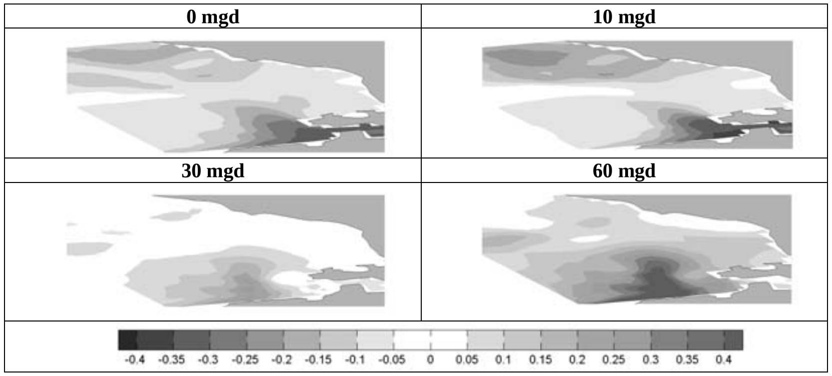

Figure 6-7: Relative additions in nitrate-nitrogen concentrations at the surface with exhibit flow included

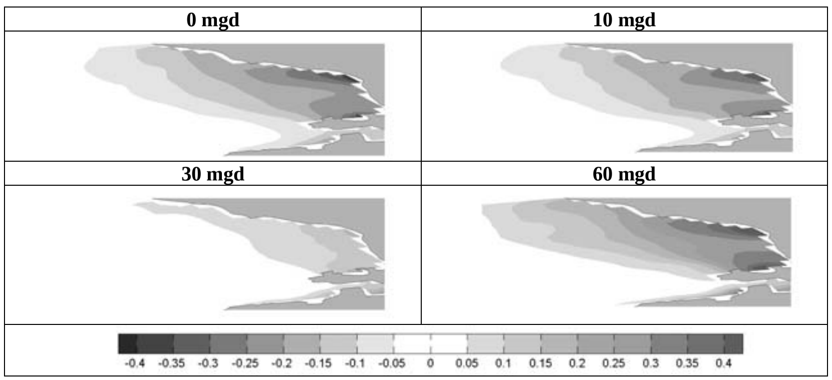

Figure 6-8: Relative additions in nitrate concentrations near the bottom with exhibit flow included

The outfall of the exhibit water into the marinas is shown to introduce a significant ammonia-nitrogen load to the system. This can also affect nitrate-nitrogen levels because in high oxygen environments, ammonia-nitrogen will convert to nitrate-nitrogen. This can be seen in Figure 6-9 and Figure 6-10, which show that concentrations outside the Harbor do not start to increase until 60 mgd of brackish groundwater are introduced to the system when the exhibit outfalls are excluded.

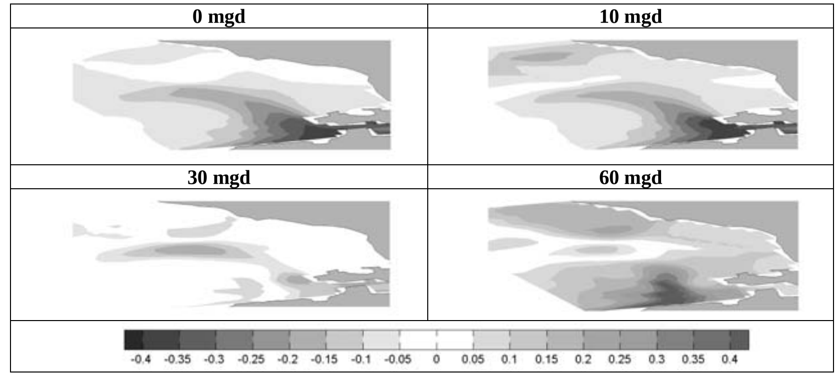

Figure 6-9: Relative additions in nitrate concentrations near the surface with exhibit flow excluded

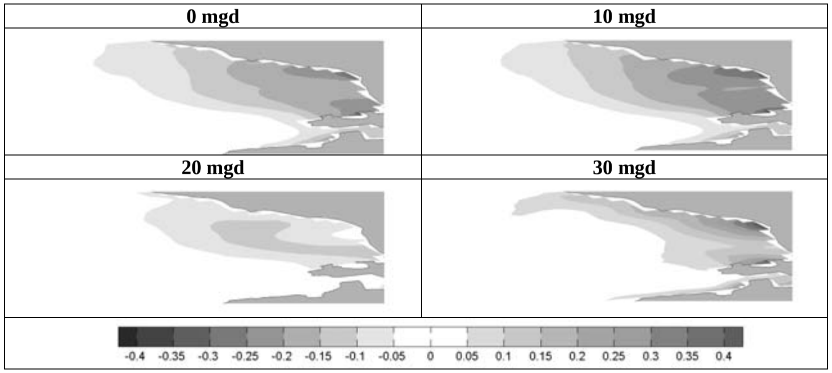

Figure 6-10: Relative additions in nitrate concentrations near the bottom with exhibit flow excluded

6.3.2 Ammonia-nitrogen

While the other nutrients are almost entirely dependent on the inflowing brackish groundwater, ammonia-nitrogen is introduced by the exhibit waters and is therefore more variable based on the alternative selected. Figure 6-11 shows the relative changes of ammonia-nitrogen outside of the Harbor at the surface with the inclusion of the exhibit flow. It is seen that in the surface waters, the highest impact occurs offshore of the Harbor, with fewer impacts near the Park coast.

Higher ammonia-nitrogen concentration levels are found in the cases with the greater amounts of brackish discharge at the surface occurs when the brackish water flowing from the new Marina is sufficiently light to mix with the ammonia from the exhibit waters and still flow out of the Marina.

The impacts in the near the bottom outside of the Harbor are more pronounced along the coast, with higher brackish discharge causing ammonia-nitrogen in the bottom layers. Also in these shallow areas, nutrients that are normally confined to the upper layers of the water column can potentially be mixed into lower layers in this region due to its shallow nature. As was shown in earlier sections, the Harbor flushing is faster when more brackish groundwater is intercepted, resulting in improved water quality. While this effect is beneficial for the Harbor waters, it results in a relative increase of nutrient loads on coastal waters increase when the water is flushed out of the Harbor.

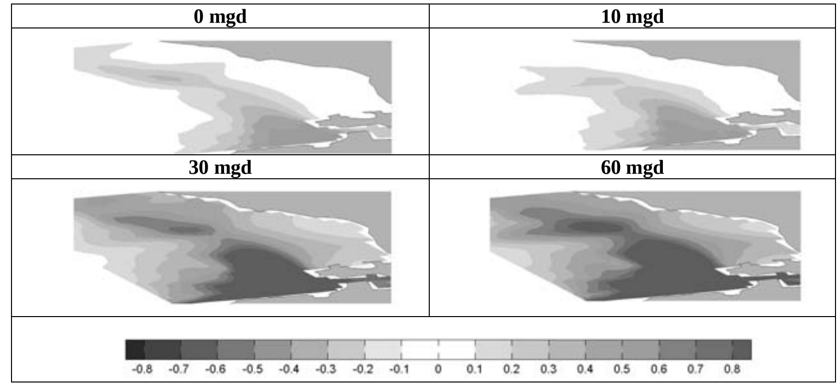

Figure 6-11: Relative ammonia-nitrogen changes from existing at the surface with exhibit flow included

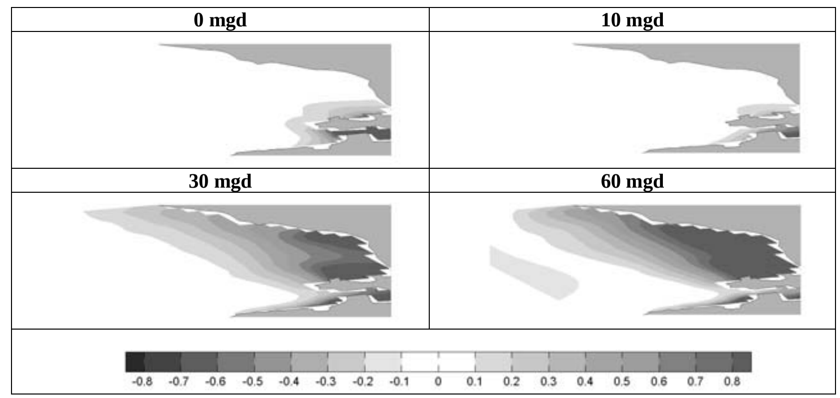

Figure 6-12: Relative ammonium-nitrogen changes from existing at the bottom with exhibit flow included

When the exhibit discharge is not considered as an input to the model, the results show that the trends of the ammonia-nitrogen concentrations follow what is shown with the nitrate-nitrogen concentrations. This is due to the fact that in this case, the main input of ammonia-nitrogen and nitrate-nitrogen is from the brackish groundwater. The results indicate that when exhibit water is not included, the relative increase is less than when exhibit water is included. This is important as the uptake of ammonia-nitrogen by coral is greatly influenced by the ambient concentrations in the bottom layer as well as the velocity effects discussed earlier.

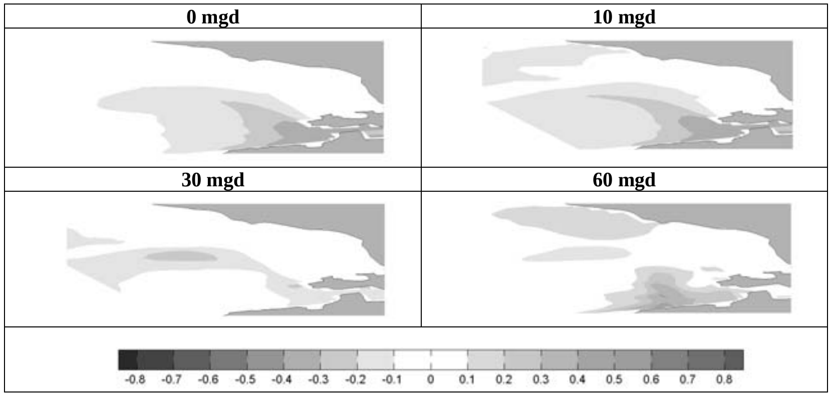

Figure 6-13: Relative ammonium-nitrogen changes from existing at the surface with exhibit inflow excluded

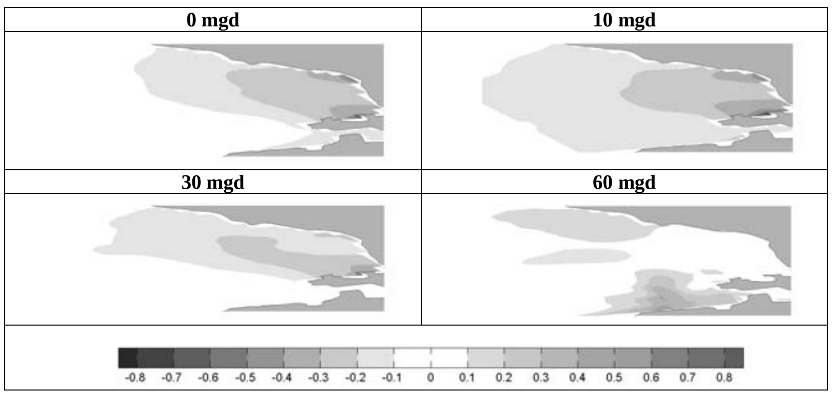

Figure 6-14: Relative ammonium-nitrogen changes from existing at the bottom with exhibit flow excluded

6.3.3 Chlorophyll a

Chlorophyll a concentrations along the coastline of Kaloko-Honokohau National Historical Park are of importance, as algal blooms and invasive algae species have been shown to be detrimental to benthic and coal communities. Current state standards mandate that concentrations within the

Honokohau Bay have a mean value less than 0.3 µg-chla/L. Ziemann (2006) reported chlorophyll levels along Transect B in the range of about 0.2 µg-Chla/L to about 1.5 µg/L, indicating that in this time period, Chlorophyll a concentrations were mainly above standards. Figure 6-15 and Figure 6-16 show the relative increase of the Chlorophyll a concentrations with the addition of the new Marina for the surface and bottom layers respectively. It is seen that surface concentrations increase much more dramatically than the bottom concentrations, especially when brackish groundwater is low and the marina system flushing is slow. This allows more algae to grow in the quiescent waters of the marinas before being released from the harbor mouth. As brackish inflow through the new Marina increases, the production of algae decreases due to the more rapid flushing out of the Harbor into more expansive waters. It can be seen that the concentration can increase by four-fold in some cases.

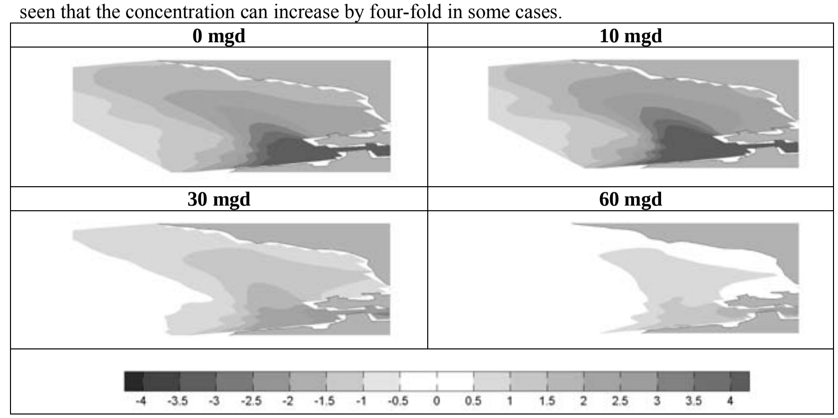

Figure 6-15: Relative increases in Chlorophyll a concentrations at the surface with exhibit inflow included

Concentrations in the bottom layers do not increase by the same relative amounts as the surface changes because of light restrictions and less available nutrients (Figure 6-16). However in the cases of lower brackish inflow, the increases can be on the order of the existing concentrations.

Simulation results indicate that when the exhibit water is not included (Figure 6-17 and Figure 6-18), the increase in Chlorophyll a production appears to be slightly higher than experienced with the diluting exhibit water.

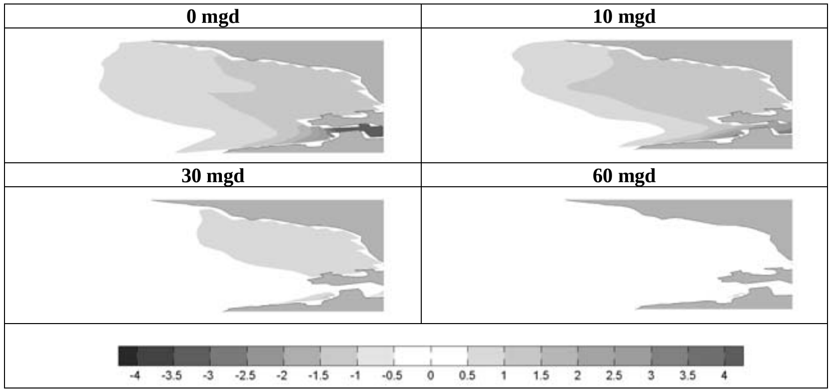

Figure 6-16: Relative increases in Chlorophyll a concentrations at the bottom with exhibit inflow included

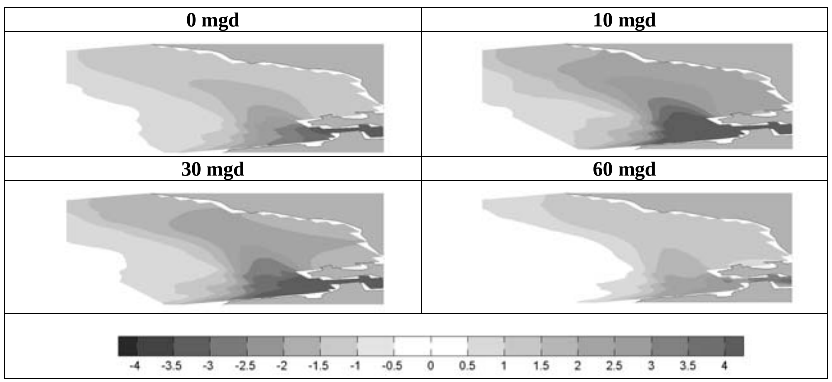

Figure 6-17: Relative increases in Chlorophyll a concentrations at the surface with exhibit inflow excluded

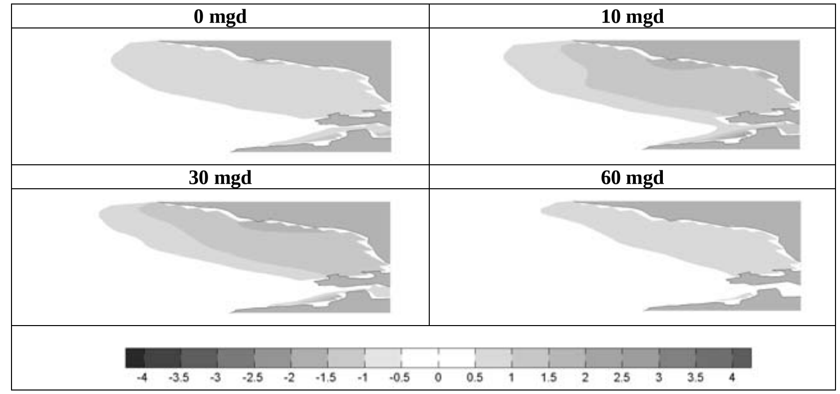

Figure 6-18: Relative increases in Chlorophyll a concentrations at the bottom with exhibit inflow excluded

6.3.4 Conclusions

Due to the increased tidal prism, exhibit inflow, and additional brackish inflow, the flow through the harbor entrance is expected to increase significantly under post-expansion conditions. Depth-averaged velocities through the harbor entrance can be increased by up to 4 times the existing conditions. This increase in velocities is limited to the harbor entrance, and changes outside of this area are not observed. Salinity differences in the surface and bottom are minimal in cases including and excluding exhibit flow.

Relative changes in nutrient concentrations at the surface tend to be higher than the changes at the bottom. When the exhibit flow is included nitrogenous nutrients tend to be higher outside of the Harbor and changes extend into the bottom layers. When the exhibit flow is excluded, the changes in nutrient concentrations tend to remain more confined to the surface layers. With higher brackish inflows, the nutrients also tend to remain more in the surface layers. Higher rates of brackish inflows lead to more nutrient inflow to the system and increases in concentration.

Change in algae growth tends to remain confined to the surface layers. Relative changes can be up to 4 times the existing concentrations. With higher brackish inflow, change in algae growth remains closer to existing conditions in both the surface and the bottom. Waimea Water Services report (2007) states that brackish groundwater entering the new Marina will be significant, so it is expected that post-expansion conditions will resemble the conditions presented for the cases with 30 mgd or higher.

7. SUMMARY AND CONCLUSIONS

The hydrodynamic and water quality existing conditions in Honokohau Harbor were analyzed with existing data sets and a numerical model. This unique system was found to be extremely complex and dependent on the high flushing rate observed under existing conditions. .

The modeled existing water quality conditions within Honokohau Harbor were compared with baseline values reported prior to the construction of the Phase II extension. Overall, Honokohau Harbor has experienced significant improvement from the baseline conditions (1980) to 1991, with corroboration from the 2006 survey (Ziemann, 2006). The concentrations of benchmark parameters NH_4 and o-P have decreased significantly since 1980, with consequent decreases in algal growth (CHLa) and DO deficit. While brackish groundwater inflows remained fairly constant in flow and concentrations, nitrate and silica concentrations increased from 1980 to 2006 in the Harbor. These increases may be attributable to lowered algal populations in the current phosphorous-limited (phosphorous-starved) system, which effectively reduces uptake of NO_3-N and silica, allowing Harbor water column concentrations to increase.

The cause of the DO sag within the Harbor at several sites (mid-Harbor and Front Berthing Basin) may be intermittent wastewater sources, which provide oxygen-demanding carbon and nitrogen loads, as well as plant nutrients. There are insufficient data to quantify the loads or to determine whether they are carbonaceous or nitrogenous. Furthermore, the nutrient data presented by (Bienfang, 1980 and OI, 1991) have very high coefficients of variability (>20%) so that the sampling stations may not be characterized sufficiently for calibration purposes.

The quantity and rate of brackish groundwater entering the existing system has been found to be important. The groundwater's high nutrient loads can be countered only by the high rate of flushing which occurs due to the density currents (low salinity water rising to the surface and flowing out of Honokohau Harbor) created by the groundwater inflow. It was found that maintaining this high rate of flushing is imperative to maintaining the water quality within the proposed system..

A hydrodynamic model was constructed and calibrated using the Delft3D integrated modeling system. This model was calibrated to existing data and applied to examine the hydrodynamic conditions within Honokohau Harbor and the surrounding areas. In addition, the model was extended to include the proposed Kona Kai Ola Marina, post-expansion conditions were examined. The quantity of brackish groundwater entering Kona Kai Ola Marina that was simulated in this study is not necessarily representative of the actual conditions that will occur upon construction of the new Marina. Instead, a range of possible values that could be expected to occur based on the available information were simulated. It is expected that the quantity of brackish groundwater into the new Marina will be significant as it has been reported by Waimea Water Services (2007) who conducted a groundwater survey and study of the project area.

It was found that the construction of the new 800-slip Marina as described in the Conceptual Master Plan causes the flushing time to increase significantly due to its large volume. This is potentially detrimental to the water quality conditions within the Harbor. It was also found that the circulation in the two harbor system is complex and contains significant internal circulation, which limits the existing Harbor's exchange with ocean waters. Under future conditions, the two

layer density driven system is affected, and during the peak ebb flow, there is not any inflowing water due to the large volume of water moving out of the system through the harbor mouth. In addition, the velocities through the harbor mouth are increased in magnitude by up to 4 cm/s during flood tide.

The hydrodynamic model was coupled with a water quality model developed for the observed conditions within Honokohau Harbor. This model was calibrated with data obtained from OI Consultants (1991) and was validated with data from Ziemann (2006). The model's calibration was within an acceptable range for all nutrients and chlorophyll a values. The calibrated model was applied to simulate future conditions including the new Marina included in the Conceptual Master Plan with 800 slips, which consisted of several possible brackish groundwater inflow rates and included the nutrient loads coming from the exhibit areas. The results show that even under the most advantageous flushing scenarios, the water quality within the existing and new Marinas is projected to decrease significantly. Elevated chlorophyll a concentrations persist outside the Harbor. This is primarily due to the decreased flushing of the Harbor post-expansion.

Based on the aforementioned results, it can be concluded that since the 800-slip marina from the Conceptual Master Plan cannot maintain existing water quality conditions it should not be given further consideration. Only if the additional brackish groundwater inflow into the new marina is determined to be greater than 60 mgd, the option of an 800 slip marina could be reevaluated

Alternatives to the Conceptual Master Plan

In order to minimize the effects of the proposed project, different design parameters could be investigated. The EPA's recommended Best Management Practices for increasing flushing of Marinas suggest a number of different options (EPA, 2001: Section 4.1).

- Changing the size or shape of the entrance channel,
- Adding more than one entrance channel,
- Using mechanical aerators in problem areas,
- Optimizing the geometry such that there are as few separated basins as possible, and
- Altering the size of the planned Marina.

In addition, due to the unique conditions experienced in the project area, alternatives associated with the inclusion and positioning of the water exhibit inflow was also considered. Within the conditions of the modeling effort, the alternative considered consists of decreasing the size (volume) of the new Marina to 400 slips (25 acres). Based on numerical model simulations, reducing the Marina volume proved to be an important factor in maintaining water quality conditions in the new marina system independently of the volume of brackish groundwater that will be intercepted by the new Marina. The positioning of the exhibit inflow also seems to affect the water quality within and outside of the marina system.

A formal solution to the proposed system is not attainable without an accurate picture of the brackish groundwater inflow to the system. The interception of large quantities of groundwater tends to increase the flushing through the harbor system which leads to more pristine conditions and less algae growth within the harbor system. This should be considered a likely post-expansion condition based on the study conducted by Waimea Water Services (2007).

Specific water quality results obtained from the 400–slips marina configuration are presented below:

1. Post-Expansion Water Quality Conditions Inside the Marina System

- Existing conditions of nitrate-nitrogen concentrations exceed standards within Honokohau Harbor and concentrations will remain similar in the existing Harbor but could improve in the new Marina due to dilution.
- Ortho-phosphate concentrations are within standards under existing conditions and they will remain similar in both marinas.
- Ammonia-nitrogen concentrations, which are within standards under existing conditions, could increase in the marina where the exhibit flow outfall is placed. This effect could be reduced by reducing the ammonia-nitrogen concentration in the exhibits flow, by reducing the amount of animals in the exhibit (pers. comm. Cloward H2O, 2007 and documented in Appendix D)
- Regarding concentration of Chlorophyll a, conditions for all simulated cases with the 400 slip marina remain within oligotrophic limits. Results showed that the chlorophyll a concentrations could remain within the Class A standards for a 400 slip marina, with the exhibit flow into the new Marina and if the additional brackish groundwater inflow into the new Marina is greater than or equal to 30 mgd, which is the same amount entering Honokohau Harbor under existing conditions.

As previously mentioned, considering the findings from Waimea Water Services (2007) stating that the "proposed marina would exhibit the same or similar flushing action" than the existing marina, and based on the results of the simulations presented in this report, it is expected that the new 400 slip marina will capture more than 30 mgd of brackish water in order to show this flushing behavior. Under these conditions and based on the numerical water quality simulations, water quality conditions in the two marina system, outside of the Marina and at Honokohau Bay will remain very similar to existing conditions. In the case that after construction, the new marina would not show the same flushing behavior as the existing marina Waimea Water Services (2007) suggests a mitigation alternative that it would be possible to enhance the inflow into the new marina by drilling bore holes in the floor of the marina in order to reach the adequate flushing.

2. Post-Expansion conditions outside of the Harbor Mouth

In general, NO_3-N, o-P and NH_4-N concentrations outside of the Harbor mouth after the new Marina construction are expected to be in the same order to those observed under existing conditions. However, Chlorophyll a concentrations appear to be consistently higher than Class AA standards; however they decrease for all cases below the standards for Class A waters. Due to the area's proximity to the Harbor entrance, this may still remain acceptable as long as the algae dies and is diluted within a reasonable distance from the Harbor mouth.

Depth averaged velocities are increased through the Harbor entrance channel by up to 4 cm/s (with a 400 slip marina); however, this increase is confined to a small area immediately surrounding the Harbor entrance.

3. Post-Expansion Water Quality Conditions at Honokohau Bay

Conditions outside of the Harbor were examined briefly, however definitive conclusions based on model results cannot be drawn due to the fact that the model was not calibrated for this region. Results can be used to determine trends of the surrounding areas. The changes in nutrient concentration vary based on the quantity of brackish groundwater. Inclusion of the exhibit waters with the simulated nutrient loads causes a significant difference in ammonia-nitrogen concentrations throughout the Bay, extending into the bottom layers in some cases. The differences in Chlorophyll a concentrations were such that they allow the areas of concern to still remain oligotrophic. In order to develop a fully calibrated model for this region, extensive data collection for calibration and validation would be needed. It was found that the significance of the brackish inflow into Kona Kai Ola Marina also has an effect on the surrounding waters. The concentrations of nutrients in low flow scenarios are relatively less than existing conditions due to the lack of additional nutrients to the system. However, with higher brackish inflow, the growth of algae is more contained.

The results obtained for the 400-slips marina suggest that if the additional brackish groundwater inflow into the new Marina is greater than or in the order of 30 mgd and reducing the ammonia-nitrogen load in the exhibit water, the water quality conditions at both marinas, the harbor entrance and Honokohau Bay will be very similar to the actual conditions.

It is also worth noting, that the following assumptions were considered reasonable and necessary to implement the model:

- The wastewater treatment plant adjacent to the project site would be upgraded to tertiary treatment without discharging directly into the groundwater.
- Measures will be taken to avoid any point or non-point sources entering the marina system, since they could modify the water quality predictions presented in this study.
- Neither waves, ocean currents, nor extreme hydrodynamic conditions were considered.
- Groundwater withdrawals would not affect the brackish inflow to Honokohau Harbor
- The unknown brackish inflow to Kona Kai Ola Marina could be between 0 mgd and 60 mgd.

Due to the uncertainties and assumptions made in the development of the numerical model, it is recommended that a significant monitoring effort be put in place during and following the construction of Kona Kai Ola Marina in order to determine the future ambient conditions and to control any additional inputs not accounted for within the model. Due to the high importance of flushing to maintaining system quality, the post-expansion option suggested by Waimea Water Services (2007) of drilling additional holes in the bottom of the new Marina and the existing Harbor could be used to enhance flushing and improve water quality if needed.

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APPENDIX A – DATA FROM PREVIOUS STUDIES

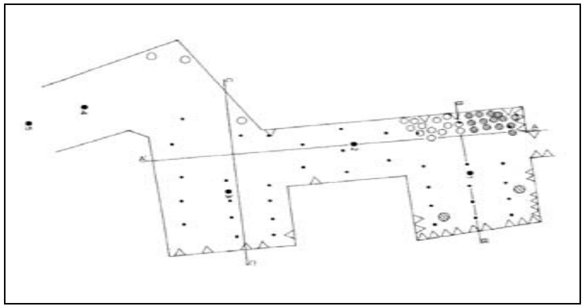

Figure A-1: Bienfang Sampling Locations (1980)

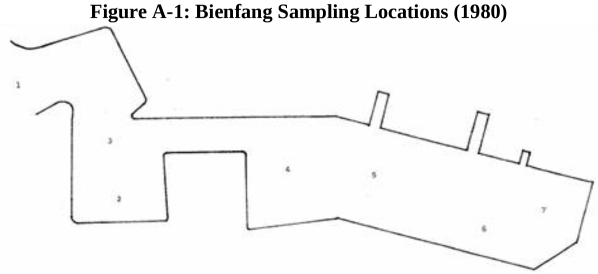

Figure A-2: Bienfang Sample Locations (1982)

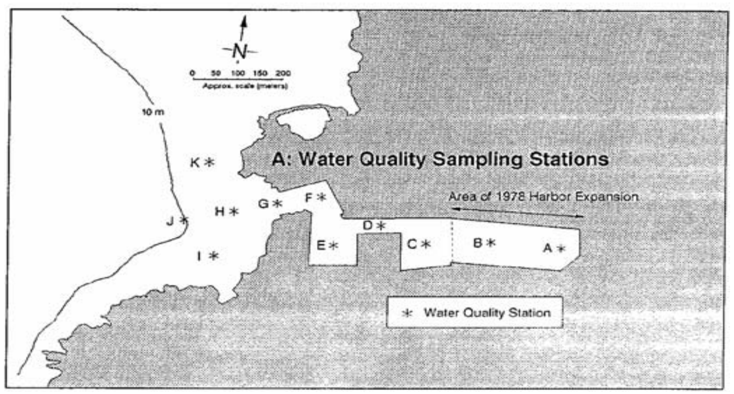

Figure A-3: OI Consultants Sampling Stations (1991)

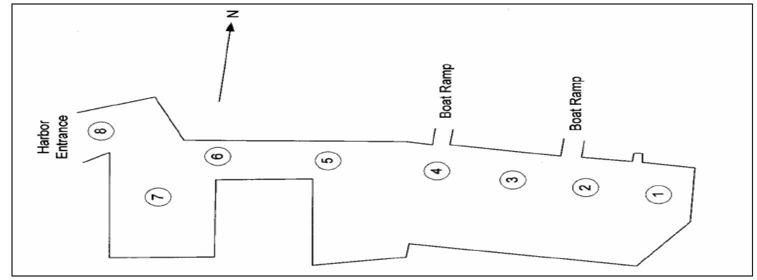

Figure A-4: Ziemann Sampling Stations (2006)

Table A-1: Surface concentrations

Surface

Study	Site	Sample Location Approx.Ziemann	Temp, oC	Sal, ppt	DO, mg/L		DO Deficit, %		NO3, ug-N/L	PO4, ug-P/L	NH4, ug-N/L	Chl, mg/m3	SiO2, ug-Si/L
Bienfang (1980) L	1	4.5	20.5	18.5	4.53		-44		381.8	60.8	18.76	0.10	
Bienfang (1980) L	3	7.0	21.5	30	5.44		-27		329	54.56	16.9	0.1	
Bienfang (1980) H	1	4.5	20.5	18.5	4.53		-44		471.2	77.5	7.70	0.06	
Bienfang (1980) H	3	7.0	21.5	30	5.44		-27		322	48.98	7.6	0.1	
Bienfang (1982) L	7	1							425.6	62.62	3.78	1.68	
Bienfang (1982) L	6	2							525	53.94	0.14	3.47	
Bienfang (1982) L	5	4							460.6	41.85	2.66	0.36	
Bienfang (1982) L	4	5							592.83	66.96	0.14	5.02	
Bienfang (1982) L	3	7							296.52	70.06	1.54	2.76	
Bienfang (1982) L	2	8							441.42	57.04	2.66	0.56	
OI (1991) L	A	1	21.42	24.06	5.34		-30		277.8	54.0	14.14	0.07	2891.4
OI (1991) L	B	3	21.65	27.09	5.49		-27		277.7	46.1	5.19	0.62	3157.4
OI (1991) L	C	4.5	21.57	26.00	5.59		-26		179.8	39.7	4.77	0.11	2582.2
OI (1991) L	D	6	21.82	27.02	5.83		-22		121.1	36.1	14.71	0.12	2188.1
OI (1991) L	E	7	22.91	27.74	5.93		-19		313.2	42.4	3.75	0.16	3168.3
OI (1991) L	F	8	22.48	27.75	6.15		-17		226.1	37.9	5.79	0.10	3003.7
OI (1991) L	G		24.21	30.97	5.87		-16		251.7	33.3	6.10	0.17	2879.5
OI (1991) H	A	1	20.88	24.27	5.34		-31		325.2	54.5	7.75	0.07	5149.5
OI (1991) H	B	3	21.78	27.64	5.50		-26		246.8	194.7	6.87	0.65	3447.5
OI (1991) H	C	4.5	21.79	26.77	7.98		6		240.6	169.5	5.79	0.07	2671.9
OI (1991) H	D	6	22.58	27.55	6.45		-13		231.9	167.3	4.95	0.10	3985.3
OI (1991) H	E	7	23.04	27.57	7.46		2		202.2	106.6	3.37	0.12	2206.1
OI (1991) H	F	8	23.87	29.21	6.74		-6		164.7	100.5	4.67	0.12	2764.2
OI (1991) H	G		24.05	31.78	7.15		2		73.5	50.4	4.07	0.32	1351.1
Ziemann (2006)	1	1	24.40	22.60	6.22		-15		660.0	22.0	1.00	0.12	10810.0
Ziemann (2006)	2	2	24.2	21.5	6.35		-14		590.0	28.0	1.00	0.09	10320.0
Ziemann (2006)	3	3	24.4	25.3	6.89		-5		389.0	14.0	1.00	0.22	11220.0
Ziemann (2006)	4	4	25.1	24.9	6.31		-12		218.0	16.0	1.00	0.43	8830.0
Ziemann (2006)	5	5	21.3	25	6.22		-19		520.0	16.0	1.00	0.11	8800.0
Ziemann (2006)	6	6	21.4	26.9	6.24		-17		596.0	22.0	1.10	0.16	7799.0
Ziemann (2006)	7	7	23	26.4	6.8		-8		640.0	27.0	1.90	0.18	9768.0
Ziemann (2006)	8	8	22.9	28.9	6.73		-7		430.0	18.0	1.30	0.20	6738.0

Table A-2: Bottom Concentrations

Bottom

Study	Site	Sample Location Approx.Ziemann	Temp, oC	Sal, ppt	DO, mg/L		DO Deficit, %		NO3, ug-N/L	PO4, ug-P/L	NH4, ug-N/L	Chl, mg/m3	SiO2, ug-Si/L
Bienfang (1980) L	1	4.5	24.5	35	5.83	6.83	-15		53.2	9.9	8.12	0.55	
Bienfang (1980) L	3	7.0	24.5	35	5.18	6.83	-24		6.7	6.5	12.88	0.24	
Bienfang (1980) H	1	4.5	24.5	35	5.83	6.83	-15		53.9	12.1	3.92	0.70	
Bienfang (1980) H	3	7.0	24.5	35	5.18	6.83	-24		17.9	9.9	8.54	0.43	
Bienfang (1982) L	7	1							8.54	11.78	3.78	55.42	
Bienfang (1982) L	6	2							14.7	6.51	4.06	35.27	
Bienfang (1982) L	5	4							11.62	17.05	3.36	15.47	
Bienfang (1982) L	4	5							4.9	3.41	3.78	6.63	
Bienfang (1982) L	3	7							0	16.43	4.06	1.38	
Bienfang (1982) L	2	8							0	4.03	6.16	0.37	
OI (1991) L	A	1	22.25	29.01	5.87	7.35	-20		170.8	36.9	10.03	1.88	2671.0
OI (1991) L	B	3	24.36	32.18	5.81	6.96	-16		140.8	26.7	6.79	3.21	2422.8
OI (1991) L	C	4.5	24.10	31.45	6.41	7.02	-9		129.3	34.1	11.25	6.40	2479.0
OI (1991) L	D	6	24.77	32.31	6.58	6.90	-5		52.6	16.0	5.75	4.44	1493.2
OI (1991) L	E	7	24.82	34.32	6.60	6.82	-3		11.9	9.3	5.33	5.47	471.1
OI (1991) L	F	7	24.75	34.09	6.49	6.84	-5		18.9	9.6	3.47	0.52	742.5
OI (1991) L	G	8	24.65	34.60	6.54	6.83	-4		40.0	7.0	7.64	0.31	734.6
OI (1991) H	A	1	23.62	30.46	8.04	7.12	13		94.5	79.3	8.21	1.44	3519.7
OI (1991) H	B	3											
OI (1991) H	C	4.5											
OI (1991) H	D	6											
OI (1991) H	E	7											
OI (1991) H	F	7											
OI (1991) H	G	8											
Ziemann (2006)	1	1	24.60	29.90	6.52	7.02	-7	8	196.0	16.0	1.00	0.56	6610.0
Ziemann (2006)	2	2	21.3	30.1	6.48	7.434	-13	8	210.0	12.0	1.00	0.25	5010.0
Ziemann (2006)	3	3	24.3	30.7	6.57	7.024	-6	8	404.0	10.0	1.00	0.55	5040.0
Ziemann (2006)	4	4	25.7	30.8	6.59	6.853	-4	8	206.0	12.0	1.10	0.54	5320.0
Ziemann (2006)	5	5	24.3	31.2	6.72	7.004	-4	8	190.0	12.0	2.80	1.16	3704.0
Ziemann (2006)	6	6	23.9	31.6	6.88	7.037	-2	8	240.0	20.0	2.90	0.90	6195.0
Ziemann (2006)	7	7	24.30	32.30	6.83	6.96	-2	8	160.0	10.0	2.20	0.58	2875.0
Ziemann (2006)	8	8	24.2	32.4	7.12	6.968	2	8	120.0	8.0	1.90	0.41	2397.0

APPENDIX B – DESCRIPTION OF FLUSHING TIME CALIBRATION

FLUSHING TIME CALIBRATION

The hydrodynamic model was used to calibrate the dispersion coefficient and the groundwater discharge rate. The data obtained during the dye study that was conducted in March 1991 was used to tune the model.

Residence Time

The concentration of a constituent within an enclosed body of water like a harbor which is dominated by tidal effects can be described by

$$C = C_0 e^{-t/T}$$

Where C_0 is the initial concentration and C is the concentration of the constituent at time t. T is considered to be the flushing time constant or the residence time of the particle. This approach is often referred to as the "e-folding" approach (Monsen *et al*, 2002). The residence time, T, can be considered to be the time required for reduction of a conservative tracer concentration to $1/e$ or 36.8% of its initial value, or a reduction of 63.2%. Mathematically, assuming an exponential distribution of times for individual water particles to reach the ocean, when the concentration of particles reaches 1/e, it represents the average time of all particles to reach the ocean.

If the natural logarithm of the above equation is written as

$$\ln(C) = \ln(C_0) - t/T$$

then it is seen that the natural logarithm of the concentration of a tracer is a linear function of the time with a slope of $-1/T$. In this way, the residence time can be estimated without knowing the initial concentration. This method of computing the residence time was used in the studies conducted by OI Consultants (1991).

Sensitivity Analysis

In this case, to follow the analysis presented in the study conducted by OI Consultants, Inc., the computation of a flushing time constant, T, was used to represent the residence time in the harbor. In order to do this, various combinations of groundwater discharge and dispersion coefficients were chosen to test the model sensitivity. The hydrodynamics for each of these combinations were coupled to a water quality module that was seeded with a conservative tracer up to the mouth of the harbor (Figure 1). This model containing the conservative tracer was then started at the point of last release of the Rhodameine dye at 13:00 March 14, 1991.

Varying the flow rate was found to be important in transporting the substance primarily in the surface layer. For example, when the flow rate was kept at a low value such as 8 mgd which is more consistent with the rates produced by Bienfang (1980) and cited in (OI Consultants, 1991), the model could not transport the substances even out of the surface layer. However using a higher flow rate of 30 mgd, which is more consistent with the rate produced by Gallagher (1980), produces a more reasonable distribution of salinity as well as a flushing time constant consistent with those reported by Gallagher (1980) and OI Consultants (1991) based on measurements within the Harbor.

The field study conducted by OI Consultants (1991) shows flushing time constants within the Harbor to be fairly depth uniform. Dispersion coefficients were varied between 0.1 m^2/s and 1 m^2/s. Independently of the flow rate it was found that using dispersion coefficients at the upper limit promoted too much mixing impacting the salinity gradients throughout the harbor. Using dispersion coefficients at the lower limit caused little to no mixing of the conservative tracer in the lower layers over the three day period. This is not consistent with what was observed in field measurements. Therefore, the dispersion coefficient was calibrated with the flow rate to provide the best results with respect to flushing time throughout the harbor and the salinity gradients that result.

Thirteen cases were tested within the parameters described above. They are presented in Table B-1.

Table B-2: Description of sensitivity cases

Case	Groundwater inflow	Dispersion
1	8	0.1
2	8	0.5
3	15	0.5
4	20	0.1
5	20	1
6	25	0.3
7	25	0.5
8	30	0.3
9	30	0.5
10	30	0.6
11	30	0.7
12	30	0.8
13	35	0.8

In order to compute the residence time for each of these cases, the hydrodynamics under these conditions were used to drive the Delft3D WAQ module. In order to replicate conditions that under the study conducted by OI Consultants (1991), the model was seeded with a conservative tracer with an initial concentration of 1 g/m^3 throughout each depth layer. Outside of the harbor the concentration was set with an initial value of 0 g/m^3. The initial conditions within the harbor are shown in Figure. This model was run at an initial time equal to the time at which the dye injection was completed, 13:00 March 14, 1991. The model was run for a four day period.

Figure B-1: Initial conditions of conservative tracer concentration (red=1, blue=0)

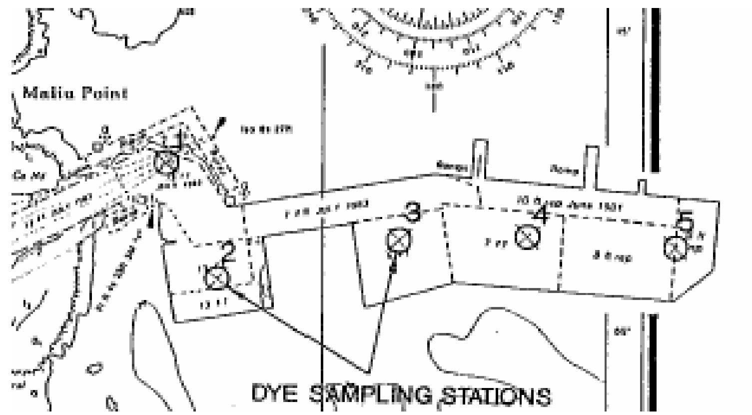

Figure B-2: Dye Sampling stations from OI Consultants (1991)

Using concentration results extracted from the model at each of the five stations shown in Figure B-2, a similar analysis was performed in order to find *T* for depths at the top, middle and bottom of the water column. The results for all tests are shown in Table B-2.

Table B-1: Flushing times

		Station 1	Station 2	Station 3	Station 4	Station 5
Case 1	Top	1.83	1.80	1.77	1.58	1.56
	Middle	2.17	1.60	1.35	0.78	0.84
	Bottom	2.28	2.50	2.27	0.87	0.83
Case 2	Top	0.88	0.89	0.91	0.92	0.93
	Middle	0.87	0.88	0.90	0.78	0.79
	Bottom	0.84	0.77	0.74	0.63	0.68
Case 3	Top	1.28	1.29	1.30	1.23	1.25
	Middle	1.31	1.23	1.29	0.85	0.79
	Bottom	1.17	0.83	0.72	0.51	0.47
Case 4	Top	1.98	1.83	1.71	1.32	1.30
	Middle	3.01	1.62	1.41	0.67	0.67
	Bottom	3.02	2.42	1.49	0.68	0.64
Case 5	Top	0.49	0.49	0.49	0.50	0.50
	Middle	0.49	0.49	0.50	0.48	0.48
	Bottom	0.47	0.47	0.47	0.44	0.46
Case 6	Top	1.06	1.05	1.05	1.02	1.02
	Middle	1.10	1.05	1.04	0.88	0.84
	Bottom	1.06	0.91	0.87	0.79	0.80
Case 7	Top	0.92	0.90	0.89	0.86	0.86
	Middle	0.96	0.92	0.94	0.71	0.71
	Bottom	0.84	0.66	0.61	0.45	0.51
Case 8	Top	1.02	1.02	1.01	0.99	0.98
	Middle	1.05	1.03	1.02	0.90	0.87
	Bottom	1.02	0.91	0.89	0.81	0.83
Case 9	Top	0.86	0.84	0.82	0.79	0.79
	Middle	0.90	0.89	0.89	0.71	0.71
	Bottom	0.79	0.64	0.60	0.46	0.52
Case 10	Top	0.60	0.60	0.60	0.61	0.61
	Middle	0.61	0.61	0.61	0.60	0.60
	Bottom	0.60	0.59	0.58	0.55	0.59
Case 11	Top	0.53	0.53	0.53	0.53	0.54
	Middle	0.53	0.54	0.54	0.53	0.53
	Bottom	0.52	0.52	0.52	0.49	0.52
Case12	Top	0.49	0.49	0.49	0.50	0.50
	Middle	0.49	0.49	0.50	0.48	0.48
	Bottom	0.47	0.46	0.46	0.41	0.44
Case13	Top	0.47	0.47	0.47	0.47	0.47
	Middle	0.47	0.47	0.48	0.46	0.47
	Bottom	0.46	0.45	0.45	0.41	0.44

Note that for tests with small dispersion coefficients (<0.5) the depth variability in the flushing time is high, which can be seen from the standard deviations at each of the stations. Case 4 had the highest variation in depth since it had both a high groundwater flowrate (20 mgd) and a low dispersion (0.1 m^2/s), so that the brackish inflow mainly stayed in the surface layer while not mixing with the saltwater in the lower layer. Both Cases (1 and 4) with dispersion coefficients of 0.1 m^2/s had high depth variation with standard deviations greater than 0.5. The test with the mean flushing time closest to that reported in OI Consultants (1991) and that reported by Gallagher (1980) was the case with 20 mgd groundwater infiltration rate and 1 m^2/s dispersion coefficient. However, this case did not meet salinity show the salinity layers well enough due to too much mixing with the high dispersion coefficient. Therefore, the best case was the case with 30 mgd of groundwater infiltration and a dispersion coefficient of 0.7 m^2/s. This yields a low variation with depth (STD about 0.1) and a mean flushing time of 0.53, which is about 12 hours as reported by Gallagher (1980).

	Station 1	Station2	Station3	Station 4	Station 5	Average Harbor
			Case 1			
Mean	2.09	1.97	1.80	1.08	1.08	1.60
STD	0.23	0.47	0.46	0.44	0.42	0.57
			Case 2			
Mean	0.86	0.85	0.85	0.78	0.80	0.83
STD	0.02	0.07	0.10	0.15	0.13	0.09
			Case 3			
Mean	1.25	1.12	1.10	0.86	0.84	1.03
STD	0.07	0.25	0.33	0.36	0.39	0.31
			Case 4			
Mean	2.67	1.96	1.54	0.89	0.87	1.58
STD	0.60	0.41	0.16	0.37	0.37	0.78
			Case 5			
Mean	0.48	0.48	0.49	0.47	0.48	0.48
STD	0.01	0.01	0.02	0.03	0.02	0.02
			Case 6			
Mean	1.07	1.00	0.99	0.90	0.89	0.97
STD	0.02	0.08	0.10	0.12	0.12	0.11
			Case 7			
Mean	0.91	0.83	0.81	0.67	0.69	0.78
STD	0.06	0.14	0.18	0.21	0.18	0.16
			Case 8			
Mean	1.03	0.99	0.97	0.90	0.89	0.96
STD	0.02	0.07	0.07	0.09	0.08	0.08
			Case 9			
Mean	0.85	0.79	0.77	0.65	0.67	0.75
STD	0.06	0.13	0.15	0.17	0.14	0.14
			Case 10			
Mean	0.60	0.60	0.60	0.59	0.60	0.60
STD	0.01	0.01	0.02	0.03	0.01	0.02
			Case 11			
Mean	0.53	0.53	0.53	0.52	0.53	0.53
STD	0.01	0.01	0.01	0.02	0.01	0.01
			Case 12			
Mean	0.48	0.48	0.48	0.46	0.47	0.48
STD	0.01	0.02	0.02	0.05	0.03	0.03
			Case 13			
Mean	0.47	0.46	0.47	0.45	0.46	0.46
STD	0.01	0.01	0.02	0.03	0.02	0.02

APPENDIX C – ANALYSIS OF WASTEWATER TREATMENT PLANT NUTRIENT LOADS

Date: February 13, 2007

To: Kona Kai Ola Project Team, File

From: Lauren Schmied, Rafael Cañizares

CC: John Headland, Russ Boudreau

Subject: Kona Kai Ola Water Quality Model
Clarification of Assumptions Regarding WWTP
M&N File 5818

A brief analysis was performed to determine the effects on the water quality of the brackish groundwater entering the system after the Marina expansion and the upgrade to the local wastewater treatment plant (WWTP). It is estimated that if the WWTP were to be left in its current state (secondary treatment), the water quality into the new Marina would contain significantly higher nutrient loads than those entering the current Harbor. This is based on the information presented in Waimea Water Services, Inc. (2006). The data presented by AECOS as an appendix in the aforementioned document shows that the nutrient values at Wells 2 and 6 are significantly higher than other wells within the Park (Table C-1). Well 2 has the highest concentrations as this is closest to the point where the wastewater is discharged (DEIS, 2006). Well 6 is shown to be proximal to the location of the new Marina, and thus the values of nutrients entering the new Marina without upgrading the WWTP would be similar to those found at Well 6. This introduces a much higher phosphorous load into the system. In the Hydrodynamic and Water Quality Modeling draft report prepared by Moffatt and Nichol (February 2007), the phosphorous concentration within the new Marina is shown to be one of the significant water quality problems facing the expansion.

Table C-1: Water Quality Conditions as reported by AECOS (2006)

	Well 2	Well 6	Harbor Spring	Quarry Well
Salinity (ppt)	4.4	18.4	25.1	5.3
Nitrate (mg-N/L)	0.54	0.59	0.42	1.20
TP (mg-P/L)	2.71	0.62	3.70	0.07
Ammonia (mg-N/L)	0.005	0.002	0.003	0.003

The DEIS (submitted December 2006) states that the existing WWTP will be upgraded to tertiary treatment and will no longer be discharged into the groundwater. In order to determine the water quality of the brackish water entering the existing Harbor and the new Marina without the effects of the WWTP effluent, the values of the Quarry Well sampling (Table C-1) were assumed to be representative of water without the effects of the WWTP as it is located upstream of the injection site. Values from Quarry Well were diluted with oceanic water (including the nutrient loads of the background ocean conditions) to the salinity of the water entering the existing Harbor (on the order of 22 ppt), resulting in values not significantly different to those already used as input to the water quality model. Table C-2shows the values reported by various

researchers of the brackish water entering the Harbor. It is seen that these values remained fairly constant over the years. Comparing these values to those computed from diluting the Quarry Well data shows that the WWTP effluent effect on the waters entering the existing Harbor is fairly negligible, and therefore the values used in the model represent brackish water with no wastewater effects. This represents the conditions that will occur upon completion of the WWTP upgrade.

If current wastewater effects were to be considered in the model, their effect to the new Marina would be significant as the phosphorous values measured at Well 6 (Table C-1), are much higher than those used within the model. It appears that the new Marina intersects the pathways of the brackish groundwater carrying the WWTP effluent from its actual discharge location, and so without an upgrade to the current system, the simulated water quality conditions would be much worse than the results presented in the Hydrodynamic and Water Quality Modeling draft report prepared by Moffatt and Nichol (February 2007).

Table C-2: Estimate of Water Quality Conditions at the New Marina location without WWTP discharge

	AECOS (2006 Harbor Spring)	Hoover and Gold (2005) (22 ppt)	Johnson *et al.* (2006) (22 ppt)	Bienfang (1980)	Model Inputs	Computed Dilution Values (2006 Quarry Well)
NO_3-N	0.42 mg-N/L	0.336 mg-N/L	0.434 mg-N/L	0.5 mg-N/L	0.42 mg-N/L	0.513 mg-N/L
PO_4-P	-	0.0465 mg-P/L	0.0589 mg-P/L	0.0744 mg-P/L	0.06 mg-N/L	0.052 mg-P/L
NH_4-N	0.003 mg-N/L	0.014 mg-N/L	-	-	0.014 mg-N/L	0.002 mg-N/L

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APPENDIX D – NUTRIENT LOADS FROM MARINE EXHIBITS (CLOWARDH2O)

DESCRIPTION OF CALCULATIONS FROM CLOWARD H2O

Nitrogen – Almost all of the nitrogen introduced into the aquarium is excreted by the fish in the form of ionized and un-ionized ammonia. Due to the rapid flushing of the exhibit tanks, (less than 3 hours for all exhibits) there is insufficient time of any significant metabolism of the ammonia to nitrite/nitrate. Each kg of feed typically produces .03kg of total N. (Timmons and Losordo, 1994)

TSS – Each kg of feed will produce 0.30kg of solids waste (Timmons and Losordo, 1994)

Phosphorous – Fish requirements for phosphorous in their diet is small, though important to proper development, particularly of the skeletal and scale structures. Most metabolic P wastes are excreted as phosphate via the urine. The levels of those P excretions are determined by plasma phosphate concentration within the animals (D. Bureau. 2004). By controlling the dietary intake of phosphorous in the animals, the excretions of phosphorous are minimized and controlled to insignificant levels.

Table D-1: Calculation of nutrients for water features

Feature	Surface Area, Acres	Surface Area, Sq.Ft.	Average Depth, Ft.	Volume, Gallons	Turnover, Minutes	Flow Rate, Gpm	Weighted Average Turnover Time, Minutes	Weighted Average Flow Rate, New Water, GPM	Lbs of Fish, based on 1 lb/100 gallons of water	Kg of Feed at 2% of body weight per day	Kgs of Suspended solids produced per day	Kgs of Ammonia produced per day as mg/l of total nitrogen TAN
Upper Lagoon	4.5	196,020	4	5,864,918	360	16,291	147.4403		0	0	0	0
Dolphin Lagoon	0.75	32,670	6	1,466,230	160	9,164	16.38225		14,662	133.2936	39.98808	3.998808
Dolphin Holding	0.2	8,712	10	651,658	160	4,073	7.281001	4887	6,517	59.2416	17.77248	1.777248
Snorkel Lagoon	0.75	32,670	7	1,710,601	70	24,437	8.361775	48874	17,106	155.5092	46.65276	4.665276
Ray Lagoon/kids touch and v	0.4	17,424	3	390,995	120	3,258	3.276451	8146	3,910	35.54496	10.663488	1.066349
Shark Lagoon	0.3	13,068	8	781,989	120	6,517	6.552901	10861	7,820	71.08992	21.326976	2.132698
Turtles and Biters	0.2	8,712	8	521,326	120	4,344	4.368601	6517	5,213	47.39328	14.217984	1.421798
Swim Lagoon	3	130,680	3	2,932,459	360	8,146	73.72014		0	0	0	0
Total	10.1	439,956	49	14,320,176	1,470	51,793	267	53,557	55,228	502.0726	150.62177	15.06218

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