

JAMES A. BAKER III INSTITUTE FOR PUBLIC POLICY
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GRUS AMERICANA AND A TEXAS RIVER:
A CASE FOR ENVIRONMENTAL JUSTICE

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***Grus americana* and a Texas River**

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Introduction

Fall in Texas, especially along the Gulf Coast, is not so much heralded by crisper air or changing leaves as it is by the arrival of millions of migratory birds, most of which are only stopping over briefly on their way to even warmer climes in Mexico and beyond. The largest and most magnificent of these nomadic species does not pass through but spends the winter season, as do many human “snow birds,” in their favored and unique location on the Texas coast. I am, of course, referring to the whooping crane (*Grus americana*).

The object of this paper is to discuss the role Texans must play for the survival of the whooping crane. We will focus primarily on the wild, free living, nonexperimental and growing Wood Buffalo-Aransas National Wildlife Refuge whooping crane population, and the importance of the Guadalupe-San Antonio River system to the survival of this endangered species during its stay in the wintering grounds in Texas.

Description

The adult whooping crane is an unmistakable bird. Standing approximately 5 feet high, it weighs in at between 14 and 17 pounds. A wingspan of 7 to 8 feet gives the crane plenty of lift for the long migratory flights between Canada and Texas. The body feathers are snow white except for black primary feathers at the wing tips and a black “mustache” sweeping back from its beak. Red skin and a few black thin feathers define the crown of the bird. A long yellow-green beak adapted for “spear fishing” or digging matches in color the bird’s golden-yellow eyes. Exposed portions of the legs and toes are black. Juvenile whooping cranes, on the other hand, have black primary wing feathers, but their body plumage is a cinnamon-mottled white that even covers the head. As the bird matures, the cinnamon color of its mottled feathers gradually diminishes to the snowy white of the adult. Interestingly, young whooping cranes have blue eyes that later turn yellowish.

Range

The whooping crane lives exclusively in North America. It is one of only two crane species living in North America. The other is the sandhill crane, found in great numbers in and around the marsh areas of coastal Texas. Although both species occupy some of the same general territory, the sandhill crane, numbering about 650,000 birds (International Crane Foundation, 2010), has several nesting areas as well as many wintering areas across North America.

The only extant natural, self-sustaining flock of whooping cranes, numbering 247 birds in 2009 (Stehn, 2010), nests and fledges at the Wood Buffalo National Park (WBNP)—located on the border between northern Alberta, Canada, and the Northwest Territory—and winters exclusively in the Aransas National Wildlife Reserve (ANWR) in Texas. Migration between Aransas and Wood Buffalo occurs in both spring and fall.

In 1975, efforts to establish a second migratory wild flock were attempted at Gray's Lake National Wildlife Refuge in southeastern Idaho. Eggs were transferred from whooping cranes at Wood Buffalo to nests of greater sandhill cranes in Idaho. These orphaned whooping cranes, however, failed to form pair bonds with each other and suffered high mortality rates. Perhaps their foster parents were unable to teach them how to be whooping cranes. Consequently, the program was discontinued in 1989 with no surviving whooping cranes.

In the 1980s, U.S. and Canadian naturalists made other attempts to establish an experimental flock as insurance in case disaster struck the Aransas-Wood Buffalo flock. In 1993, 33 captive-reared cranes were released at the Kissimmee Prairie of central Florida to establish a nonmigratory flock. After multiple bird additions, this flock numbered 87 in 2001 but is now dwindling and was down to 29 in 2009.

In 1999, governmental, nonprofit, and private organizations united to form the Whooping Crane Eastern Partnership (WCEP) to establish a new, migratory flock of whooping cranes trained to migrate between Wisconsin and coastal Florida. Chicks were conditioned to follow an ultra-light aircraft at the Necedah National Wildlife Refuge in central Wisconsin. The aircraft guided them

on their first migration south. In the fall, the young whooping cranes and a team of pilots and biologists began the 1200-mile journey to Chassahowitzka National Wildlife Refuge in Florida. The birds now spend the winter in Florida and return unassisted to Wisconsin in the spring. In 2009, this flock numbered over 100 birds and appears to be successful.

The whooping crane population at one time covered a much larger geographic range. Fossil remains dating back several million years have been found in Pleistocene formations throughout Florida (International Crane Foundation, 2010; S. L. Olson, 1972). Pleistocene fossils or prehistoric remains are also catalogued from sites in California (Miller, 1927), North Dakota, Illinois, Idaho, Michigan, Kentucky, Virginia (Brodkorb, 1967), and Arizona (Cracraft, 1968). Miller (1928) describes the Pleistocene record rather poetically. He states:

“Again we find the asphalt beds of McKittrick and of Rancho La Brea telling a comparable story of the freshwater migrants. Snow Geese, Gray Geese and White-fronted Geese, Sand-hill and Whooping cranes, a host of bare-footed mud-probers such as Red-backed Sandpipers, Long-billed Dowitchers, and Yellow-legs, pattered or stalked about the Pleistocene marsh or wedged across the sky in a landscape picture that is hard to dissociate from the tang in the air which often forces even the sluggish unfeathered biped to at least a local migration.”

Whooping cranes, although extending from central Canada to Mexico and from California to the Atlantic coast, probably never gained major abundance. Their numbers were thought to be around 1500 in the mid-1800s. The number of birds and their species range shrank rapidly in the second half of the nineteenth century. Except for a small nonmigratory population living in southwestern Louisiana, breeding birds had disappeared from all historic U.S. breeding sites by the 1890s. By 1900, ornithologists were predicting that the whooping crane was “doomed to extinction.” Habitat loss and land use change due to westward expansion of settlers, unregulated hunting for sport and food, and the popularity of egg and specimen collecting at the turn of the century were the major factors leading to the species decline (International Crane Foundation, 2010).

Governmental Protection

From 1918 to the present, the Migratory Bird Treaty Act has protected the whooping crane, along with most American migratory birds. This statute states that it is unlawful to pursue, hunt, take, capture, kill, or sell birds listed therein (“migratory birds”). The statute does not discriminate between live or dead birds and also grants full protection to any bird parts, including feathers, eggs, and nests. The Migratory Bird Treaty Act does grant the secretary of the interior the authority to establish hunting seasons for any of the migratory game bird species listed in the statute. In actuality, the U.S. Fish and Wildlife Service (USFWS) has determined that hunting is appropriate only for those species for which there is a long tradition of hunting, and for which hunting is consistent with their population status and their long-term conservation. Although the Migratory Bird Treaty Act lists some 170 species to be “game birds,” less than 60 species are typically hunted each year. The whooping crane is on this list, but there has never been a designated hunting season for it. Subsequent laws now protect the whooping crane.

In spite of this act, by 1945 only a remnant of a formerly stable population survived, and this remnant leads a precarious life because of the species’ conspicuousness—its large size and white plumage—and its migratory habits. For many reasons, it is a marvel that whooping cranes have held on as long as this (Stevenson and Griffith, 1946). As a case in point, the Louisiana flock, which contained 13 birds in 1938, was down to one bird in 1947 and vanished by 1950. Similarly, in 1941 the Aransas-Wood Buffalo flock contained only 16 birds and was barely holding its own (International Crane Foundation, 2010). Happily, this flock numbered 247 birds in 2009 because of the active protection provided by the governments of the United States and Canada.

Literally inspired by the plight of the whooping crane, Congress passed the Endangered Species Preservation Act in 1966. The law authorizes the secretary of the interior to make a list of endangered domestic fish and wildlife and allows the Fish and Wildlife Service to spend up to \$15 million per year to buy habitat for listed species. It also directs federal land agencies to preserve endangered species habitat on their lands “insofar as is practicable and consistent with their primary purpose.” The whooping crane was listed as endangered throughout its range on

March 11, 1967. With the support of the Nixon administration, Congress, by an almost unanimous vote, passed the completely rewritten Endangered Species Act of 1973. The new law distinguishes threatened from endangered species, allows listing of a species that is in danger in just part of its range, allows listing of plants and invertebrates, authorizes unlimited funds for species protection, and makes it illegal to kill, harm, or otherwise “take” a listed species. In effect, the law makes endangered species protection a very high priority of the government. The whooping crane remains an endangered species to this day. Whooping cranes currently are protected in Canada, where they are classified as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), created in 1977 as a result of a decision made at the Conference of Federal-Provincial-Territorial Wildlife Directors held in 1976 in Fredericton, New Brunswick.

Breeding Habitats

Extending over 11 million acres, Wood Buffalo National Park is Canada’s largest national park and one of the largest in the world. The park plays a key role in the preservation and protection of the whooping cranes by providing and protecting the nesting habitat of the last remaining Canadian migratory flock. The park was originally established in 1922 to protect the free-roaming bison herds of the area. The fact that the whooping crane nested in the park was not known until discovered in 1955. The nesting area for the whooping crane is located in the remote north-central corner of the park. It is a fragile complex of marshes, shallow ponds and lakes, streams, and bogs. There is no public access. Today, the park supports and protects diverse ecosystems containing several rare species besides the whooping crane (Parks Canada, 2010).

The cranes usually arrive at WBNP in late April or early May, just as the ice and snow are melting from the marshes. They need to arrive by early spring in order to begin nest building in a timely fashion. The young chicks will need to utilize the entire short summer to grow, learn to fly, and gain endurance for the migration with their parents in fall. Thus the adult pair takes only a few days to select a place to nest, showing considerable preference for the same general area where they have previously nested. Several pairs have been observed to nest in the same areas for as long as 22 years. They usually build their nests at ground level on small islands of grassy

wetland sedges where hopefully the young are relatively protected from predators. The female crane normally lays two eggs, but generally only one chick survives. If both chicks are lost, there is usually not enough time to start a second brood before it is time to leave for the journey south. Both male and female share incubating the eggs until they hatch in approximately 30 days. The young birds are not ready to fly until they are about 80 or 90 days old. The juvenile has only a short time to develop skill in flying because the family needs to be ready to depart before the first freeze, usually in early October (U.S. Fish and Wildlife, 2007).

These nesting territories, termed “composite nesting areas,” vary considerably in size, ranging from about 0.8 to 29 square miles, averaging approximately 2.5 square miles or 1,600 acres. Adjoining pairs usually nest at least 0.6 miles apart; however, nests have been recorded as close as 435 yards from each other. From the initiation of egg laying until chicks are a few months of age, the activities of pairs and family groups, including foraging for food and water, are restricted to their specific breeding territory (U.S. Fish and Wildlife, 2007). The principal foods of the whooping crane in their breeding territory are mollusks and crustaceans, insects, minnows, frogs, and snakes. Thus, the nesting territory must contain a diverse ecosystem and be chosen carefully.

The Northern Boreal Plains of the Wood Buffalo Park provide such habitats. It is characterized by a poorly drained, flat topography. The uniform relief, porosity, and solubility of the bedrock have produced a drainage type that is primarily vertical and percolating rather than horizontal across the surface of the land. Water percolating through the soil and bedrock causes saturation of the plains surface. This has created karst landforms in areas of gypsum bedrock. Other phenomena include salt flats, underground streams, sinkholes, and saline streams. The boreal plains are a mosaic of muskeg, meandering streams, shallow lakes and bogs, and boreal forest, an ideal habitat for the foraging whooping crane. Wood Buffalo National Park is also a home to many species of wildlife typical of the northern boreal forest, some of which are predators of the juvenile whooping cranes. Bears, wolves, moose, lynx, marten, wolverines, foxes, beavers, and snowshoe hares are but a few of the wild mammal species found (Parks Canada, 2010).

Migration Habitats

The distance between the whooping crane breeding grounds in Canada and the wintering grounds in Aransas, Texas, is approximately 2,500 miles. Flying at about 30 mph, they cover between 200 and 400 miles per day at altitudes from 1,000 to 6,000 feet. Actual speeds, altitudes, and daily distances depend on wind and weather conditions as well as conditions on the ground between flights. The migration route is long but narrow (about 300 miles wide). The migration route is through Texas, Oklahoma, Kansas, Nebraska, South Dakota, and North Dakota in the United States, and Saskatchewan and Alberta in Canada. Cranes rest and feed in all these states. The central part of the Platte River in Nebraska has been considered “the most valuable part” of the whooping crane’s entire migration route. It is composed of wet meadows, sloughs, and crop fields along the river and shallow waters in the river where the birds can roost at night. Most whooping cranes that stop on the Platte River spend only a few days before continuing their migration, but a few have tarried more than a month on the Platte. Not all whooping cranes stop on the Platte River but do use wetlands, small lakes, and ponds in other states along the migration corridor. Whooping cranes generally migrate as individuals, pairs, or family groups. At times they may form small flocks of between five and 35 birds. On occasion, one or two individual whooping cranes can be observed migrating with flocks of sandhill cranes. Whooping cranes generally migrate during daylight hours, but can originate before sunrise and/or continue after sunset, thus spending less time on the ground and covering large distances in a migration day. Fall migration tends to be longer than spring migration, probably because of the biological need to nest early in the spring (The Crane Trust, 2010). The bird’s first fall stop often occurs in northeast Alberta or northwest Saskatchewan, about 310 miles southeast of their departure area in WBNP. Local weather conditions influence distance and direction of travel, but whooping cranes generally are capable of reaching the autumn staging grounds in the north-central portion of the Saskatchewan agricultural area on the second day of migration. Most of the cranes remain there for two to four weeks while they feed on waste grain in barley and wheat stubble fields and roost in the many wetlands. The remainder of the migration from Saskatchewan to the wintering grounds at ANWR is usually rapid, probably weather-induced, and may be completed in a week. Food intake during migration is not well documented but probably includes frogs, fish, plant

tubers, crayfish, insects, as well as agricultural grains. The largest amount of time on the ground is spent feeding in harvested grain fields (U.S. Fish and Wildlife, 2007).

Winter Habitat in Texas

Aransas NWR was originally established by President Franklin D. Roosevelt in 1937 as a “refuge and breeding ground for migratory birds and other wildlife ... for use as an inviolate sanctuary, or for any other management purpose, for migratory birds ... and to conserve (A) fish or wildlife which are listed as endangered species or threatened species ... or (B) plants.” The refuge complex comprises more than 115,000 acres, including the Blackjack Peninsula (Aransas proper), Matagorda Island, and other smaller units. About 22,000 acres of salt flats on ANWR and adjacent islands are used as winter territories by the whooping cranes.

Aransas NWR provides vital resting and feeding wintering grounds for the whooping crane as well as other migratory birds and native Texas wildlife. It is one of more than 545 national wildlife refuges spanning the United States and managed by the U.S. Fish and Wildlife Service. The National Wildlife Refuge System is the only national system of lands dedicated to conserving our wildlife heritage for today and generations yet to come.

Whooping cranes occupy the Aransas NWR and adjacent areas from October to April, or over half the year. Pairs and families generally occupy and defend discrete territories averaging approximately 290 acres. Sub-adults and unpaired adults congregate in small flocks outside areas of family territories (U.S. Fish and Wildlife, 2007).

A thesis by Lafever (2006) contains much of what is known about whooping crane behavior in their winter habitat. She investigated spatial and temporal winter behavior and behavioral responses of five territorial whooping crane families at Aransas National Wildlife Refuge during the winters of 2003-2004 and 2004-2005. The five whooping crane territories observed ranged from the northern end to the southern tip of Blackjack Peninsula in Aransas County. All territories studied were adjacent to the Gulf Intracoastal Waterway (GIWW) or adjacent to a bay located on the GIWW. Territories were primarily composed of salt-marsh habitat, which can be

described as a mosaic of marsh vegetation and intermittently inundated ponds. Inundation and salinity of ponds varied throughout the year, depending on tidal cycles, precipitation, and freshwater inflows from the Guadalupe and San Antonio Rivers located north of Blackjack Peninsula. Observations were conducted from December 2003 through April 2004, and October 2004 through April 2005.

As might be expected, both adult and juvenile cranes spent the majority of the day foraging (63 percent and 66 percent, respectively). Alert behavior comprised 15 percent of the cranes' time-activity budgets; preening or resting, and movement each constituted approximately 7 percent of the time-activity budget. Adults were more alert than juveniles in January-February. The proportion of time spent on other behaviors did not differ by age.

Overwinter use of territories varied spatially and temporally. Flight occurrence was highest in November-December, coinciding with establishment of territorial boundaries upon arrival at the wintering grounds. Movement velocity (meters traveled/minute) also tended to be highest in November-December, which may be due to territorial defense and foraging activities. Use of land, open water, and edge habitats (land and water interface) within territories appeared to fluctuate with primary food item availability. Disproportionate use of land habitat by several crane families coincided with peak production of wolfberry (*Lycium carolinianum*) fruit, which occurs in November-December. Edge habitat was used disproportionately to its availability throughout the winter, most likely because this habitat type provided refuge for blue crabs (*Callinectes sapidus*), an important food item for whooping cranes. Several families also used open water disproportionately to its availability.

The winter diet of whooping cranes consists predominantly of blue crabs along with various species of clams, and the plant wolfberry. The wolfberry matures at about the time the crane arrives at ANWR and is essentially gone by the end of December. After that, most food foraging occurs in the brackish bays, marshes, and salt flats on the edge of the mainland and on barrier islands. In a year of high crab abundance, whooping cranes can consume seven to eight crabs per hour (80 crabs per day), totaling 80-90 percent of their diet. In contrast, during years of low blue crab abundance, cranes consume an average of only three crabs per hour (about 35 crabs per

day). The average abundance of blue crabs in the San Antonio Bay system varies throughout the year. The crab population is relatively low during the months of November through January. It is high during the rest of the time the whooping crane is in residence.

The blue crab lives in estuarine and tidal areas and other shallow coastal waters, to a maximum depth of around 90 meters. It is found on muddy and sandy bottoms in coastal areas, but may move to greater depths in cold winters. When air temperatures drop below 50°F (10°C), adult crabs leave shallow, inshore waters and seek deeper areas where they bury themselves and remain in a state of torpor throughout the winter. In this state they are unavailable to the whooping crane.

Blue crab growth is regulated by water temperature. Growth occurs when water temperatures are above 59°F (15°C). Water temperature above 91°F (33°C) is lethal. Blue crabs are susceptible to sudden drops in temperature.

Salinity is important to the blue crab, but requirements vary by life stage. Generally optimum salinity is 3-15 parts per thousand (ppt). Maximum abundance is between 10 and 20 ppt. Below 5 ppt and above 30 ppt the blue crab is absent. Larvae are sensitive to salinities below 20 ppt, but juvenile and adult crabs can cope with everything from freshwater to highly saline marine conditions. After mating, the female will migrate to high salinity waters in lower estuaries, sounds, and near-shore spawning areas. They overwinter before spawning by burrowing in the mud. Most females spawn for the first time two to nine months after mating, usually from May through August the following season. Larvae are filter feeders, and live a planktonic existence in the high-salinity surface waters near the spawning grounds, as do the pre-juvenile megalops. The juveniles gradually migrate into shallower, less-saline waters in upper estuaries and rivers where they grow and mature. Males generally migrate farther upstream, preferring low-salinity waters, whereas females tend to stay in lower rivers and estuaries. Sexual maturity is reached after 18 to 20 post-larval molts, generally at the age of 1 to 1 1/2 years. Males continue to molt and grow after they reach sexual maturity. It is generally accepted that females cease to molt and grow (terminal molt) when they mature and mate and the cycle repeats itself.

The juvenile crabs are the preferred diet for the whooping crane and generally can be found in the marshes of their territory. Marsh, sea grass beds, and wetlands are crucial for blue crabs to flourish. Juvenile crabs avoid predation by seeking refuge in these habitats, and a symbiotic relationship develops between them and the vegetation. Crabs strip the aquatic vegetation of grazing mollusks and, in turn, are provided with extra cover and food—circumstances under which strong recruitment is almost guaranteed.

However, consider the effects of a prolonged drought without water restrictions. It starts with less flowing of freshwater into the estuary from the San Antonio and Guadalupe Rivers. This is followed by reduced primary productivity (growth of algae, sea grass, and phytoplankton). This reduction limits the food supply for organisms at the lower levels of the food chain (zooplankton, mollusks), which in turn limits the food supply of blue crabs. Such a sequence leads to fewer crabs for the whooping crane to eat, causing them to become excessively stressed or threatened (Sutton, 2005).

Occasionally, cranes fly to upland sites, requiring freshwater to drink when their territorial waters become too saline. Whooping cranes do not drink water that is more saline than 23 ppt. While upland, they may take foods such as acorns, snails, crayfish, and insects, and then return to the marshes to roost. Uplands are particularly useful when partially flooded by rainfall, burned to reduce plant cover, or when food is less available in the salt flats and marshes. Agricultural croplands adjacent to ANWR are rarely visited.

High fall tides and heavy rains sometimes flood tidal flats. In these circumstances, the birds forage almost exclusively on blue crabs and wolfberry in flooded areas. In December and January, tidal flats typically drain as a result of lower tides, and the birds move into shallow bays and channels to forage primarily on clams, although blue crabs are occasionally captured while probing the bottom. Clams are a significant dietary item when water depths are low, temperatures cold, and following drought when the blue crab population is low. Smaller blue crabs (5 cm or less in width) are preferred and are swallowed whole. Larger crabs, when eaten, are pecked into pieces before being swallowed (U.S. Fish and Wildlife, 2007).

Threats to the Whooping Crane in Texas

SEC. 4. [16 U.S.C. 1533] of the 1973 Endangered Species Act lists five categories of factors detrimental to the well-being of the whooping crane. These factors are as follows:

- The present or threatened destruction, modification, or curtailment of its habitat or range
- Overutilization for commercial, recreational, scientific, or educational purposes
- Disease or predation
- The inadequacy of existing regulatory mechanisms
- Other natural or manmade factors affecting its continued existence.

The U.S. Fish and Wildlife International Recovery Plan for the whooping crane (USFWS, 2007) details a variety of threats that address these categories. These threats are (A)-1 human habitat; (A)-2 freshwater inflow; (B)-1 shooting; (B)-2 disturbance; (C)-1 diseases and parasites; (E)-1 life history; (E)-2 food availability/sibling aggression: climate factors; (E)-3 loss of genetic diversity; (E)-4 red tide; (E)-5 chemical spills; (E)-6 collisions with power lines; (E)-7 fences and other structures; (E)-8 collisions with aircraft; and (E)-9 pesticides. Although several of these threats may appear to be solely from natural causes, all are or can be influenced through human intervention. Human habitat, shooting, chemical spills, pesticides, disturbance, and collisions with various human appliances are obviously directly associated with human intervention. Human intervention in the case of loss of genetic diversity, red tide, life history, and food availability is less direct, but can be affected by aggressive management such as that done by the U.S. Fish and Wildlife Service and the Canadian Wildlife Service. One threat that at first appears to be of natural origin but in reality is greatly influenced by human actions is the question of freshwater inflow. Maintaining an adequate supply of freshwater inflow to San Antonio Bay may very well be the single most important factor determining the future sustainability of the world's population of wild whooping cranes.

Effects of Freshwater Inflow

Freshwater is essential to crabs, and there are more crabs in the bays when freshwater is plentiful. The highest commercial blue crab catch in San Antonio Bay, according to one study, came during three years when the Guadalupe River was pouring 3 million acre-feet of water annually into the bay. How much freshwater is the right amount? The answer is hard to come by. Floods may come and wipe out the oyster reefs for a couple of years. Droughts may do the same thing. No one seems to worry about too much freshwater in the bays, but drought is a concern. The last great drought began in 1948 and ended in 1957. During its peak in 1956, the bays received 14 percent of their average freshwater inflows. San Antonio Bay received only 196,000 acre-feet of water, or 8.4 percent of its average. Up and down the coast, the oyster crop disappeared, white shrimp declined drastically, the high salinity in Upper Laguna Madre blinded black drum and scored them with lesions, and the blue crab population in the estuary dropped.

Without sufficient freshwater from the Guadalupe-San Antonio Rivers, the salinity of the estuary system can approach that of seawater at approximately 35 ppt. A salinity of that magnitude negatively affects the blue crab and the wolfberry populations, as well as those of other organisms that are all vital sources of food for the whooping crane. A higher salinity also causes the whooping crane to seek fresher water away from the relative protection of its territory.

But what is a sufficient flow of freshwater needed to sustain a healthy ecosystem in the estuary?

The drought of record is the baseline for scientific study of the freshwater inflows. Such factors as historical inflows, nutrient and sediment loads, circulation, and salinity patterns were studied and compared to a fisheries analysis to determine how much water is needed to sustain the productivity of San Antonio Bay. Similar studies have been performed for other estuaries of the Texas coast, and numbers have been produced stating the amount of water needed to keep the bays relatively productive, provided the water is distributed in a seasonal pattern (Berryhill, 2003). The value for San Antonio Bay is estimated to be 1.1 million acre-feet—about a third of what is available in a water abundant year (Texas Parks & Wildlife Department [TPWD], 2007). The modeled maximum harvest freshwater inflow (Max H) is slightly below the median flow of

1.5 million acre-feet annually. In the Guadalupe Estuary, blue crabs are most abundant in salinities that average between 10 and 25 ppt. TPWD data suggests that water inflows greater than 1.3 million acre-feet annually result in low enough salinities in the estuary to produce high numbers of blue crabs. In San Antonio Bay, the years with the highest harvests all had inflows greater than 3 million acre-feet. Therefore, according to Longley (1994), the salinity level should remain between 10 and 20 ppt for approximately 60 to 80 percent of the time for maximum production of the blue crab species as well as the white shrimp, gulf menhaden, and brown shrimp.

Whooping crane territories in the ANWR area include brackish marshland pools. With sufficient water flow and normal tides, these pools are connected to each other and with the flowing waters of the estuary system. This allows for a flow of water that keeps these pools at a salinity level at a value low enough for the whooping crane to draw its drinking water. Normally, tides in this area are highest in November-December and lowest in February-March. If the flow of freshwater into the marsh system is also low during these later months, the marsh pools may become disconnected from the bay system. Evaporation at this time, especially if the temperature is warm, will deplete these pools of water that no longer can be replaced. This condition would result in the marsh having much higher salinities than the bay itself. In fact, the salinity may become higher than 35 or 40 ppt, or much higher than the maximum salinity of 23 ppt of water that is drinkable by the whooping crane. This condition would cause the whooping crane to seek water outside its territory. It could explore territories of other whooping cranes for water that might result in aggressive behavior from the occupant crane and possible injury to the crane. It might also fly upland where the water is fresh, but where there is a higher probability of the crane being attacked or possibly killed by resident predators or by ingesting pesticides. These conditions might also lead to many whooping cranes to congregate at the same watering place, resulting in the chance for a diseased or parasite-carrying crane to infect others.

A chart of whooping crane winter mortality expressed as a percentage of the flock population and the corresponding average river flow into the Guadalupe Estuary from the combined Guadalupe and San Antonio Rivers during the six month critical period of bay productivity from July to December is shown ordered by year (1988-2009) in Figure 1a, and ordered by river flow

in Figure 1b. Flow data is obtained by combining data collected by the U.S. Geological Survey (USGS) at the Victoria, Texas, Gauge Station (USGS 08176500) in the Guadalupe River and at the Goliad, Texas, Gauge Station (USGS 08188500) in the San Antonio River. It is expressed in units of 1000 cubic feet per second. Whooping crane mortality during the winter seasons at Aransas NWR was collected by Tom Stehn of the USFWS (2009).

Figure 1a does not suggest an apparent linear or exponential correlation between mortality and river inflow. Figure 1b does show clearly that a high rate of winter mortality (>1.1 percent) always occurs during years of low water flow. In the 13 years recorded with inflows equal to or less than 2,350 cu ft/sec, the average winter mortality rate was 2.81 percent of the whooping crane population, whereas in the eight years with inflows greater than 2,300 cu ft/sec, the average winter mortality rate was 0.38 percent of the population. Using these data, we hypothesize that mortality greater than 1.1 percent is associated with total river flow during the test months of less than 2,350 cu ft/sec. The data could be organized like this in a Fisher 2x2 exact probability test:

	Flow		
Mortality (percent)	<2.35	>2.35	Total
<1.1	6	8	14
>1.1	7	0	7
Total	13	8	21
P = 0.0148			

Knowing that over a period of 21 years, 13 of these years had average July to December flow rates less than 2,350 cu ft/sec and eight had flow rates greater than 2,350 cu ft/sec and that in seven of these years the whooping crane mortality was greater than 1.1 percent, what is the probability that the years of high mortality would be so unevenly distributed between years of high and low river inflow? Invoking the null hypothesis by postulating that there is no correlation between river flow and crane mortality, and using the Fisher 2x2 exact probability test, the probability of the observed distribution of flows and mortality can be calculated exactly (one tailed test). The Fisher Exact Probability Test is an excellent nonparametric technique for analyzing discrete data (either nominal or ordinal), when the two independent samples are small

in size. It is used when the results from two independent random samples fall into one or the other of two mutually exclusive classes (NIST/SEMATECH e-Handbook, 2010).

For our particular distribution of mortality and river inflow, the probability that they are not correlated (the null hypothesis) has a P value of only 0.0147. Thus the chance that mortality and river inflow are indeed correlated as suggested is very significant. Other variables must also play an important role in whooping crane deaths. For example, Gil de Weir (2006) conducted a very thorough study of the demographics of the whooping crane wherein she considers several environmental variables such as extreme temperature, heavy precipitation, salinity, food scarcity, hurricanes, and drought that might also cause winter mortality of whooping cranes. Here we are concerned only with deaths at ANWR. There is also a high mortality rate of hatchlings and the very young juveniles at WBNP. Plus, predators are always present, not only at the breeding grounds and along the flyway, but also at ANWR.

River Inflow and Whooping Crane Mortality

The quantity and quality of freshwater that enters the Guadalupe Estuary System has a direct but complicated bearing on the well-being and, indeed, the survival of the whooping crane population that winters there. Currently low-flow years are not infrequent. Any additional loss of freshwater flowing into the bay system would significantly increase the number of low-flow years and seriously threaten the continued existence of the whooping crane.

Freshwater inflow comes primarily from the San Antonio and Guadalupe Rivers. Because Matagorda Island separates the estuary and bay system from the Gulf of Mexico, there is little direct exchange between San Antonio Bay and Gulf waters, although some exchange of salt water from the Gulf to the Bay does occur via Pass Cavallo to the north and Cedar Bayou to the south.

The Guadalupe River begins in two forks in western Kerr County, the north and south forks. These two branches converge near Hunt, Texas. From there the river continues to flow southeast for 230 miles, passing through Kerr, Kendall, Comal, Guadalupe, Gonzales, DeWitt, and

Victoria counties. It then forms the boundary between southern Victoria County and Calhoun County and between Calhoun and Refugio counties before reaching its mouth on San Antonio Bay. By the time the river reaches Victoria (USGS gauge #8176500 at Victoria), its flow rate averages about 2,005 cu ft/sec (1.453 million ac ft/yr). The minimum annual flow was 131.6 cu ft/sec (95,300 ac ft/yr) in 1956 and the maximum annual flow was 6,993 cu ft/sec (5.063 million ac ft/yr) in 1992.

The San Antonio River originates in central Texas near San Antonio and follows a roughly southeastern path through the state. The 240-mile-long river crosses five counties: Bexar, Goliad, Karnes, Refugio, and Wilson. It eventually feeds into the Guadalupe River about 10 miles from San Antonio Bay. Its average discharge (1940-2008) is 825 cu ft/sec (597,300 ac ft/year) measured at Goliad (USGS gauge #8188500). The annual freshwater contribution of the San Antonio River to the San Antonio Estuary system is about half that of the Guadalupe River, but because it passes through the San Antonio public water system, it has a much higher nutrient content.

The Guadalupe's drainage area is about 6,070 square miles while the basin area of the San Antonio River is about 3,921 square miles, or roughly two-thirds as large as the Guadalupe River basin. Together they collect runoff and spring water from an area that is nearly 10,000 square miles. Freshwater inflow to San Antonio Bay is realized primarily from these two rivers with a small additional amount from direct coastal runoff and from ungauged small creeks and streams that empty into the estuary-bay system. Legislatively mandated studies to determine freshwater inflows necessary to conserve healthy productivity of San Antonio Bay recommend 1.15 million ac ft/yr or roughly half of the average annual freshwater inflow from the Guadalupe and San Antonio Rivers. As stated previously, the Texas Parks & Wildlife Department data suggest that water inflows greater than 1.3 million acre-feet annually result in low enough salinities in the estuary to produce a healthy number of blue crabs. A level of flow this abundant produces a bay salinity of from 10 to 25 ppt. These freshwater flows are necessary to provide suitable drinking water for the whooping crane. Otherwise, they would be required to fly inland to find fresh drinking water (TPWD, 1998). Tragically, no mechanisms to guarantee critical river flows are provided by Texas water laws.

Grus americana and a Texas River

In 2000, the San Marcos River Foundation applied for a water right that would leave 1.15 million acre-feet in the river, in accordance with the flows recommended by TPWD for the Guadalupe estuary. The application was denied in 2003 but was appealed and, in February 2005, was sent back by the court to the Texas Council on Environmental Quality for a rehearing. Conservation flows were proposed in Senate Bill 3 in the Texas Legislature in 2005 and passed by the House in 2007 (International Recovery Plan, 2007). The law creates an extensive public process, soliciting input from scientists and stakeholders in each river basin to determine how much water is needed to keep the state's rivers and coastal estuaries healthy, and how to ensure that water is protected. Final flow allocations will be determined by the Texas Commission on Environmental Quality (Texas WaterMatters, 2010). The process is ongoing and subject to considerable political debate. No immediate decision is evident.

In 2002, American Rivers named the Guadalupe on their annual list of the 10 most endangered rivers in the United States because of the inflow issue. "If the state of Texas doesn't take action to ensure that water keeps flowing in the river, existing and proposed diversions could dewater the river and deprive San Antonio Bay and Aransas Bay of needed freshwater," said American Rivers President Rebecca R. Wodder (Sierra Club, 2002). Projections indicate the river will be significantly threatened during periods of low flow and could cease to flow into the bay if all currently authorized water-use permits are utilized (National Wildlife Federation [NWF], 2004).

In a report titled *Bays in Peril*, a "danger" ranking was given to San Antonio Bay because drought periods were predicted to increase by 250 percent, and years with low freshwater pulses in the spring were calculated to increase 26 percent from naturalized levels (NWF, 2004). Texas Water Development Board data indicate natural droughts already threaten the Guadalupe ecosystem. Withdrawals of surface and groundwater for municipal and industrial growth are predicted to leave insufficient inflows to sustain the ecosystem in less than 50 years. Modeling indicates that if all existing water rights were exercised during a repeat of the 1950-1956 droughts, estuary inflows would be reduced by 17 to 43 percent below current levels and by 36 to 72 percent below historic levels, depending on the year (Norman Johns, National Wildlife Federation, Austin, TX, pers. comm., in Fitzhugh and Richter, 2004). Additionally, there are

pending water right applications for much of the remaining unappropriated water in the Guadalupe (International Recovery Plan, 2007).

Water rights continue to be granted on the Guadalupe, even though some sections of the river are already over-appropriated. Greater San Antonio will continue to grow, with population expected to double by mid-century (San Antonio Water System, 2003). In stream reservoir construction, water diversions and water usage will continue to increase in the future, further reducing freshwater inflows. The Guadalupe and San Antonio rivers are a major source of water for Region L of the Texas Water Plan. Projected total water demand for south central Texas (Region L) is the sum of water demand projections for municipal, industrial, steam-electric power generation, mining, irrigation, and livestock uses. Projected changes in the total water demand by use category from 2000 to 2060 are: municipal, 187 percent; industrial, 179 percent; power generation, 362 percent; mining, 159 percent; agricultural irrigation, -21 percent; and livestock, unchanged. The total expected increase in water usage amounts to an increase in demand for river water by approximately 150 percent (SCTRWPG, 2010).

The Added Threat from Future Climate Change

Most of Texas, climatologically, has a modified marine climate. It is classified as “subtropical,” with four zones:

- The eastern third of Texas has a subtropical humid climate that is most noted for warm summers.
- The central third of Texas has a subtropical subhumid climate characterized by hot summers and dry winters.
- The broad swath of Texas from the mid-Rio Grande Valley to the Pecos Valley has a subtropical semi-arid climate.
- The basin and plateau region of the Trans-Pecos features a subtropical arid climate that is marked by summertime precipitation.

The marine climate is caused by the dominant onshore flow of tropical moist air from the Gulf of Mexico. This airflow is modified by a decrease in moisture content from east to west, as well as

by intermittent seasonal intrusions of drier continental air. The four zones of subtropical-humid, subhumid, semi-arid, and arid account for the changes in moisture content of the flow of Gulf air across the state (Larkin and Bomar, 1983).

The Guadalupe River Basin falls mainly in the subtropical subhumid zone. Current annual precipitation levels in this area range from a low of 25 inches in the west to 40 inches in the east. The Intergovernmental Panel on Climate Change (IPCC) precipitation levels for the entire region are predicted to fall by 5 to 20 percent by 2100. The IPCC (2007) predicts a positive temperature change of 3.5°C (6.3°F) or more in this same area.

As the climate warms, evapotranspiration will increase with a subsequent loss of soil moisture, and the net amount of water added to the watershed (precipitation minus evaporation) will certainly decrease. Thus the consequences of climate change are predicted to result in a temperature increase of 3.5°C (6.3°F) and a net decrease in annual precipitation of 15 percent along the Guadalupe River and, subsequently, on San Antonio Bay by the year 2100.

A climate study appearing in May 2007 (Seager et al.) models the hydroclimate in the southwestern United States using the A1B climate scenario, which amounts to a very rapid economic growth with a balance of many different energy sources and a mid-century peaking of the world population. This paper presents convincing evidence that both precipitation and evaporation will decrease over the next several decades consistent with the above estimates. The authors assert, “There is a broad consensus among climate models that this region will dry in the 21st century and that the transition to a more arid climate should already be underway. If these models are correct, the levels of aridity of the recent multiyear drought or the Dust Bowl and the 1950s droughts will become the new climatology of the American Southwest within a time frame of years to decades.”

In the current case of the Guadalupe River, by the time the river reaches USGS gauge #8176500 at Victoria, its flow rate averages about 2005 cu ft/sec (1.453 million ac ft/yr). The average is, however, far from normal. It is often said of the Guadalupe River that a normal flow is not normal! The years from 1951 through 1956 were severe drought years in South Texas. During

this time, the flow of the Guadalupe River stayed below 1000 cu ft/sec, averaging only 508 cu ft/sec. This is only one-eighth of the average flow and far below the water needed for a healthy San Antonio Bay, not to mention human needs along the lower river. The largest annual flow rate occurred in 1992 and was nearly 7,000 cu ft/sec, resulting in flooding conditions along the river. Flows in other years are almost randomly distributed.

River flow depends primarily on runoff from precipitation over the entire watershed and secondarily from springs in the Edwards Aquifer. The Guadalupe River watershed is 6,070 square miles in area. An average flow rate of 2005 cu ft/sec or 1.453-million ac ft/yr predicts a required runoff from 6,070 square miles of 0.37 ft (112 mm). A study (Reed, Maidment, and Patoux, 1997) using model calculations and observed data suggests a relationship between precipitation and runoff for precipitation levels above about 700 mm/year to be related in a linear fashion by the equation

$$R = 0.510P - 339.1 \quad \text{(Equation 1)}$$

where R = runoff in millimeters (mm) and P = precipitation in mm. This equation predicts that for an expected runoff of 112 mm, the predicted precipitation for that runoff would be 884 mm or 35 in/year.

Although we do not have a complete precipitation data set for the entire river basin, a proxy value for San Antonio might serve to test the relationship between precipitation and river flow. Annual precipitation data from 1936 to 2007 for San Antonio is available from the National Weather Service Forecast Office Austin/San Antonio. A plot of the river flow at Victoria vs. precipitation at San Antonio shows the data to be somewhat scattered with a tendency for higher flow rates at higher precipitation rates. A least squares analysis of the data yields a best-fit linear relation of

$$F = 50.6 * P + 466 \quad \text{(Equation 2)}$$

where F = Annual flow rate (cu ft/sec) from the Guadalupe Basin and P = Annual precipitation (inches) at San Antonio.

From equation 2, a postulated precipitation rate of 35 in/yr equates into a calculated flow rate of 2,237 cu ft/sec, a value quite close to the average reported observed flow rate of 2,005. It is interesting to note that for a given precipitation rate of zero, the flow rate is still 466 cu ft/sec. This figure would correspond to water input from sources other than precipitation runoff, such as from springs in the Edwards Aquifer. The two major springs contributing to the flow of the Guadalupe River are the San Marcos Springs and Comal Springs, located on the down dip of the Edwards Aquifer in the Guadalupe River Basin. The summed measured “expected” flow from these springs is given as 457 cu ft/sec (Reed, Maidment and Pateau, 1997). This value is very close to the intercept value of 466 cu ft/sec in equation 2, above.

Using the above data, the effect of climate change on the Guadalupe River can be estimated. Two aspects will be discussed: 1) the change in frequency of drought events and 2) the decrease in the general flow from the Guadalupe Basin.

Assuming that climate change will result in a decrease in precipitation of 15 percent by the year 2100, differentiation of equation 1 shows that the ratio of the change in runoff to precipitation is 0.510, or the basin runoff is reduced by approximately 50 percent of the change in precipitation, or 7.5 percent. If the probability distribution of annual flows remains the same except for a shift of -7.5 percent in the actual flow values, then the average annual flow will drop from 2005 to 1840 cu ft/sec and the number of years with annual flow of 1000 or less cu ft/sec will increase from 17 to 23. The most probable flow rate (9 years) is 401-600 cu ft/sec. The average river flow change from 2005 cu ft/sec to 1840 cu ft/sec corresponds to a decrease of 120,200 ac ft/yr in the annual flow of water from the Guadalupe River to San Antonio Bay.

The San Antonio River also supplies freshwater runoff to San Antonio Bay. On the average, this flow adds about a third of the flow from the Guadalupe River. The climate change caused reduction in the annual flow of this river will be approximately 42,000 ac ft/yr. This would bring the total reduction in the freshwater river inflow to the San Antonio Bay to essentially 162,200 ac ft/yr, a very significant loss of renewal water.

Another factor when considering the health of San Antonio Bay is the loss of freshwater through increased evaporation caused by climate change. The IPCC (2007) projected temperature change by 2100 directly along the coast of the Gulf of Mexico is approximately 3.0°C. Using data generated by Gerald North (2008), the change in open water evaporation due to a temperature increase in the Guadalupe River Basin is about 0.15-0.16 inches per month per 1°F rise in temperature. Therefore, an increase of 5.4°F (3.0°C) is 0.81 to 0.86 inches per month, or approximately 10 inches per year. San Antonio Bay is approximately 130,000 acres in size. An additional annual loss of 10 inches of water due to increased evaporation caused by climate change means that 108,300 additional ac ft of freshwater input (from Guadalupe and San Antonio Rivers) would be required in order to maintain a stable salinity.

In summary, the effects of climate change on the hydroecology of the Guadalupe River and San Antonio Bay are severe. A summary of projected climate changes and resulting effects on this system are given in Table I.

In a warming world where the Texas State Water Board projects that Texas' water demand will increase 27 percent by 2060, no gain in rainfall actually would be a loss. However, a precipitation loss of 15 percent by the end of this century will be of serious concern when attempting to satisfy this demand. Our water resources are already vulnerable and climate change predictions consistently suggest that the situation will only become worse within the next several decades.

In bays and estuaries such as San Antonio Bay, behind the barrier islands separating the Texas mainland from the Gulf of Mexico, freshwater and saltwater combine to create the environment that marine life need to live and flourish. The state's aquaculture industry is particularly sensitive to adequate amounts of freshwater and periodic increases in salinity. Because of climate change, evaporation rates in the bays will increase and replacement freshwater from river flow into lagoons and bays will decline. The effect on the bays will be much higher salt concentrations, less nutrient input, and less frequent flushing resulting in lower water quality overall. Salt tolerance of some species may be exceeded, causing changes in the food web, a reduction in marine productivity, and subsequent decline of bird species, especially the whooping crane.

Threat to Whooping Cranes by Increased Need for Electric Power Generation

The large projected increase in the population of Texas will require increased industry and business as well as more electrical power. All will require freshwater from the rivers. The number of people living currently in region L of Texas (the watersheds of San Antonio and Guadalupe Rivers) is approximately 2.5 million. This number is expected to grow to 4 million by 2050, an increase of 60 percent. The number of people in San Antonio alone is projected to increase from 1.35 million in 2010 to 2.3 million in 2050, an increase of 70 percent. The direct requirement for more municipal water to satisfy this increase in people will be high, but the projected increase in cooling water needed for the production of new electrical power for this increased population will be even more significant.

New power plants will need to come on line in order to meet an increased demand for electricity. Because of the requirement for large amounts of cooling water, these plants will of necessity be built on or near to bodies of water. Exelon Corporation is one of the nation's largest electric companies with 10 nuclear power plants throughout the United States. It has applied for an "early site permit" (ESP) with the Nuclear Regulatory Commission (NRC) for an 11,500-acre site in Victoria County to build a new nuclear power plant (NRC, 2010). If approved, the early site permit would effectively reserve the property for new nuclear construction for up to 20 years with the possibility of renewal for another 20. Unlike a combined construction and operating license, an early site permit does not authorize construction of a new plant nor does it require details on the type, number, and size of the reactors.

Although no specific plant design has been chosen for the Victoria site, Exelon Corporation presented a set of bounding plant parameters for future site development. This plan is based on the addition of power generation consisting of one or more reactors or reactor modules. These reactors or groups of modules (the number of which may vary depending on the reactor type selected) would be distinct operating units. Each unit would consist of a plant of one or more modules that would not exceed 4500 Megawatt thermal (MWth) of nuclear generating capacity (NRC, 2010).

Of the 104 nuclear power reactors currently licensed to operate in the United States, 69 are pressurized water reactors (PWR) and 34 are boiling water reactors (BWR). Both types of reactors operate on similar principles. In both systems, a closed water system flows through the reactor core and is heated by its thermal energy.

In a PWR, the water is maintained under high pressure over 2,000 psi so it does not boil even when heated to temperatures near 500°F. The heated water travels through a steam generator where it exchanges heat with a separate water system at lower pressure, turning it to steam. This steam then drives a turbine that produces electricity. The steam exits the turbine and is condensed by cooler river water. The condensed water cycles back through the steam generator where it goes through another cycle.

In a BWR, the water flowing through the reactor is directly turned to steam at or near the normal boiling point. The steam spins the turbine generating electricity. The steam then enters a condenser where it exchanges heat with isolated river water, condenses and returns to the reactor for another cycle (UCS, 2007).

The river cooling water is either passed through the system once, heated, and returned to the river (once-through cooling system) or discharged into a cooling pond where it cools to ambient temperature and recycled through the system (closed-loop cooling system). The proposed Exelon reactor will more than likely be cooled by a closed-loop system because the ESP calls for a 4,900 acre cooling pond on site. The ESP reads: “The cooling basin is one of the major features on the site. The cooling basin has a surface area of about 4900 acres. The cooling basin is part of the nonsafety-related cooling system that has the design function of dissipating the heat load in the circulating water system. The basin is formed by approximately 11 miles of perimeter embankment dams that consist of clay or clayey sand fill that are constructed above ground. Internal earth dikes inside the cooling basin will be used to guide the circulating flow from the cooling basin outfall structure to the cooling basin intake structure to optimize the effective cooling area.”

Both types of reactors operate at near 33 or 34 percent efficiency. The ESP states that a total of 4500 MWth of capacity will be generated at each of the reactor modules. This would amount to about 1500 Megawatt electric (MWe) per reactor module. The company indicates in a press release that it will generate about 3,000 MW of electrical power, enough to serve 1.85 million typical Texas homes. It also indicates that Excelon is planning on two modules (Excelon, 2008). Excelon also indicates that the electricity produced will be used for a constant “base load” demand rather than responding to “peak load” changes in electrical usage demands, and therefore the reactors will operate 24 hours a day every day.

The amount of water needed for cooling the system is the amount of water necessary to exchange 4500 MW of thermal power. This amount of water is essentially independent of reactor type and method of cooling. In a closed-loop cooling system, the net amount of water removed from the river is makeup water that is supplied to the cooling basin intermittently throughout the year. This water compensates for the inventory lost due to evaporation, blowdown, and seepage. “Blowdown” is the portion of the circulating water flow that is removed in order to maintain the amount of dissolved solids and other impurities at an acceptable level. Evaporation losses result from the operation of both the circulating water system and any applicable ultimate heat sink and auxiliary cooling-system cooling towers. The cooling basin inventory also accounts for a very small drift loss from the applicable cooling towers. Other than the river, the only natural inflow into the cooling basin is direct rainfall because the cooling basin is self-contained and has no other contributing drainage area. The cooling basin receives return effluents from the various plant’s facilities and systems, not including the radiation waste discharges.

The COLA that Excelon originally filed in 2008 estimated that this makeup water would not exceed an average of 75,000 acre ft/year. This represents 75,000 acre ft/year less entering San Antonio Bay, a situation that certainly will adversely affect the salinity of the system and, consequently, the health of the whooping crane.

Summary

Of all the natural winter sites historically habited by the whooping crane all over the United States, including the entire Texas Gulf Coast, only the Aransas National Wildlife Reserve remains viable. Why the whooping crane has chosen this place above all others to spend the winter is a mystery, yet it is an amazing fact. It surely must be because ANWR has the best available climate with the most favorite food, favorable water, and minimally disturbed territory, or else some other location would have won the selection by the bird. I believe that all of these contributing factors are at risk and therefore so is the whooping crane. Historically, as has been pointed out in this paper, 13 of the last 21 years had river inflow from the Guadalupe-San Antonio Rivers low enough to stress the whooping crane. In seven of those 13 years, an excessive fraction of the birds died. The future is even less bright. Human populations in the river basins are predicted to increase by 60-70 percent in the next 40 years. These new people and related industrial requirements will place heavier usage on the rivers, depleting and polluting the crane's habitat. Increased population means increased electrical power needs. Coal-fired power plants as well as nuclear reactor-powered electrical generators require large amounts of cooling water from the rivers. By 2100, climate change will decrease river inflow by 7-8 percent due to increased temperature in the basins. Inland precipitation will decrease by 15 percent and coastal temperature increases will increase evaporation from San Antonio Bay by over 108,000 ac ft/yr. Climate change alone will increase the frequency of low annual flow by 35 percent. At best, the whooping crane is currently under threat from poor freshwater inflow into the San Antonio Bay system. The future looks much more bleak and will take all of the technological goodwill and know-how that we as humans can muster in order to stabilize or perhaps, if we are really smart, increase health and well-being of our fellow Texans, the whooping cranes.

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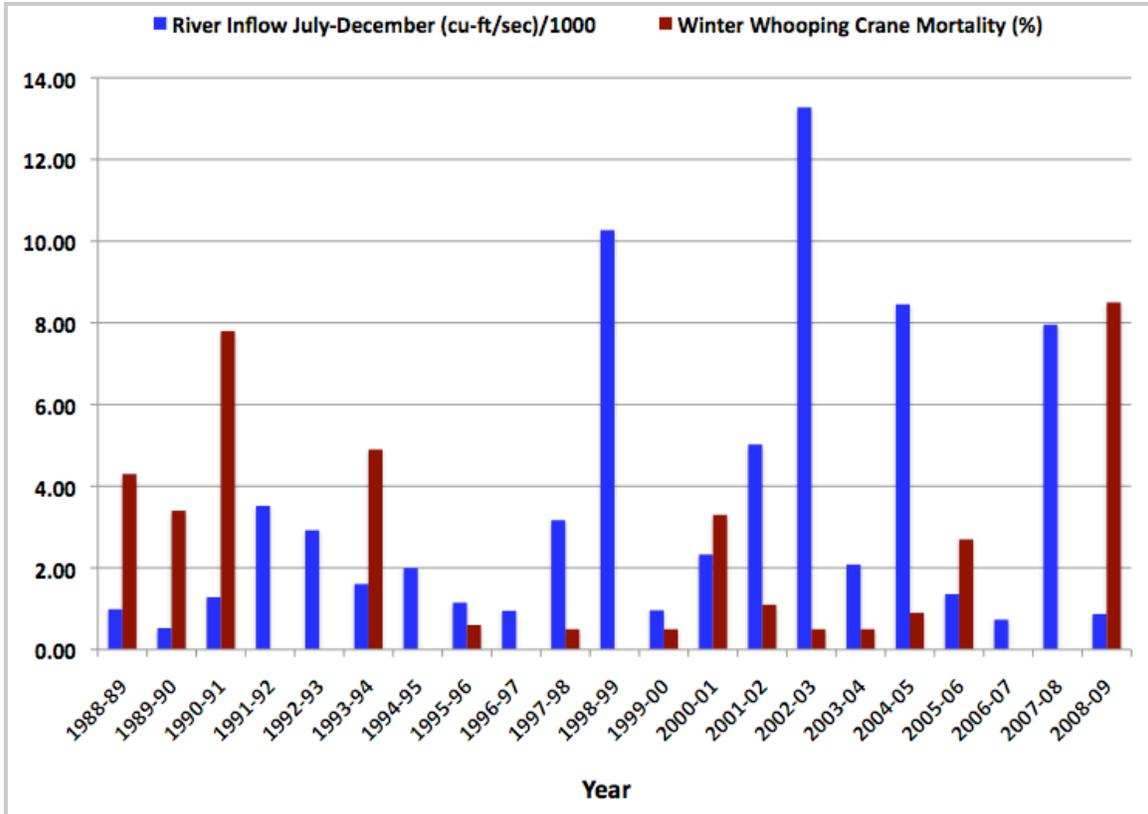


Figure 1a. A chart of whooping crane winter mortality expressed as a percentage of the flock population and the corresponding average river flow into the Guadalupe Estuary from the combined Guadalupe and San Antonio Rivers during the six month period from July to December is shown ordered by year (1988-2009).

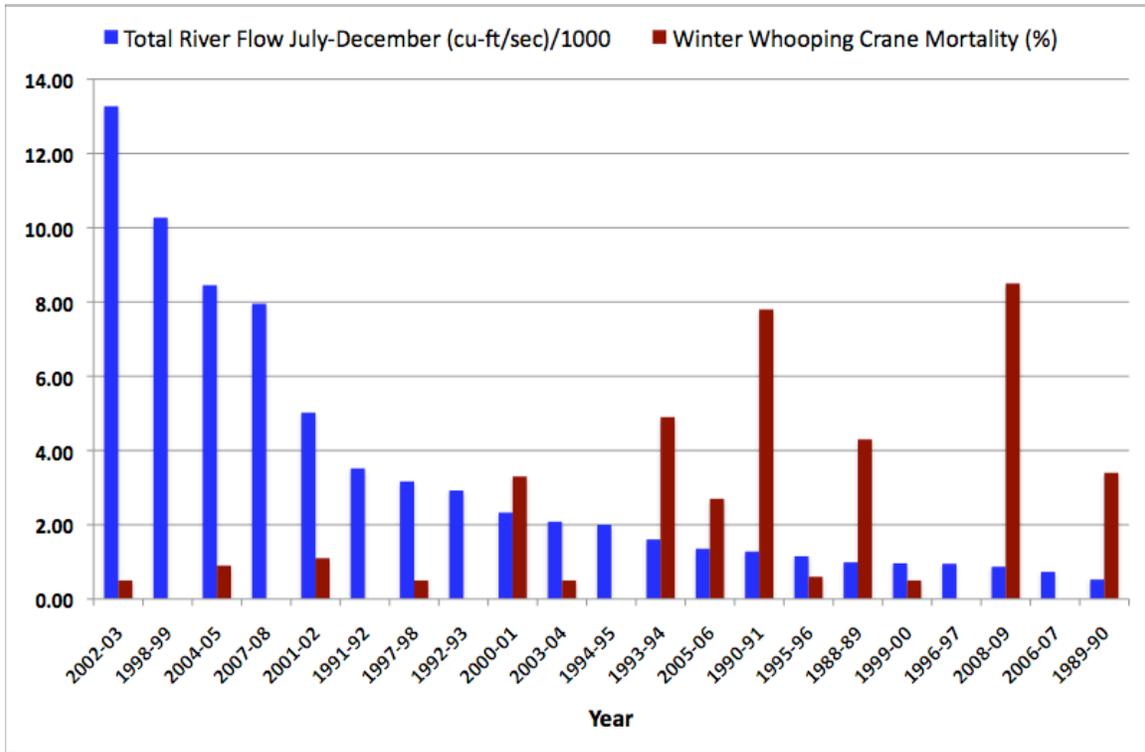


Figure 1b. Same data as in Figure 1a, except it is ordered by decreasing river flow from July to December.

Table 1. A summary of climate changes from the present to 2100 and the resultant effect on the hydrology of the Guadalupe River and San Antonio Bay.

Climate Change Cause	River-Bay System Effect
River basin temperature changes by >3.5°C	Annual river basin runoff decreases by 7-8 percent
Inland Precipitation decreases by 15 percent	Average river flow decreases by 120,200 ac ft/year in Guadalupe River and 42,000 ac ft/year in the San Antonio River.
	Frequency of years with annual flow less than 1,000 cu ft/sec increases by 35 percent
Coastal temperature changes by 3.0-3.5°C	Evaporation from San Antonio Bay increases by 108,000 ac ft/year, resulting in a total freshwater deficit of 270,200 ac ft/yr with respect to current climate conditions.