The Inaugural
D. R. F. Harleman Honorary Lecture in Environmental Fluid Mechanics

Saving Venice from the Sea

by

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Applied Research Auditorium

The Pennsylvania State University
Department of Civil and Environmental Engineering
College of Engineering
University Park, PA 16802

DONALD R. F. HARLEMAN HONORARY LECTURE IN ENVIRONMENTAL FLUID MECHANICS

The Harleman Lecture serves to honor Dr. Donald R. F. Harleman, who distinguished himself in the fields of hydraulics and environmental engineering as a student and a member of the faculty at the Massachusetts Institute of Technology (MIT) from 1945 through 1991, when he retired as professor emeritus. He currently holds the title of Senior Lecturer at MIT.

The Lecture was established by an initial grant in November of 2001 from Joseph R. Reed, Professor Emeritus of Civil Engineering at Penn State. It was formally approved in February 2002 by the University's Board of Trustees as the "Donald R. F. Harleman Endowment in Environmental Fluid Mechanics". The endowment will be supplemented in the future through an estate plan bequest made by Dr. Harleman in July 2002 .

The Harleman Lecture is intended not only to enrich the faculty and students in the hydrosystems division of Penn State's Civil and Environmental Engineering Department, but also the entire engineering community external to the Department as well, by providing contact with outstanding researchers and practitioners in the field from outside the University. The lecture will be a fall semester parallel to the very successful Kavanagh Lecture in Structural Engineering established in 1994 and held annually in the spring.

PROGRAM

Opening Remarks………………………………………… *Dr. Arthur C. Miller*
Professor of Civil Engineering
The Pennsylvania State University

Welcome……………………………………………………. *Dr. Andrew Scanlon*
Professor and Head
Civil & Environmental Engineering
The Pennsylvania State University

Introduction of Speaker………………………….………. *Dr. Joseph R. Reed*
Professor Emeritus of Civil Engineering
The Pennsylvania State University

Harleman Honorary Lecture….. …………………. *Dr. Donald R. F. Harleman*
Ford Professor of Environmental Engineering, Emeritus
Massachusetts Institute of Technology

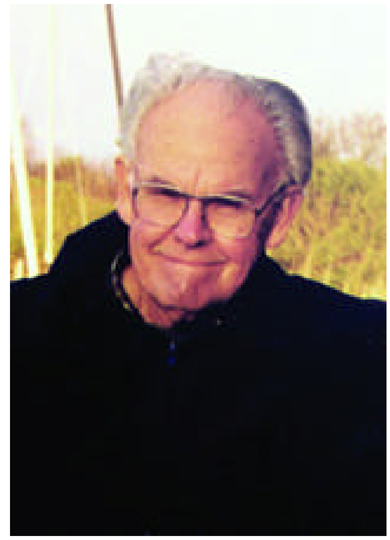
Questions and Answers…………….……………. *Drs. Miller and Harleman*

Presentation……………………….…………………………….. *Dr. Reed*

Closing Remarks……………………...……………………… *Dr. Miller*

Reception

Donald R. F. Harleman



Donald R. F. Harleman, a native of Palmerton, PA, received his B.S.C.E. degree from Penn State in 1943 and his M.S. and Sc.D. degrees in Civil Engineering in 1947 and 1950 from the Massachusetts Institute of Technology (MIT). He worked as a design engineer for Curtis-Wright Corporation in Ohio during WWII. Through 1962 he held research and faculty positions in Hydraulics at MIT, and in 1963 he became Professor of Civil Engineering. He was appointed Ford Professor of Environmental Engineering in 1975, and achieved Emeritus status in 1991. He currently holds the title of Senior Lecturer at MIT.

Dr. Harleman has been an active member of the National Academy of Engineering and is an Honorary Member of the American Society of Civil Engineers (ASCE). He has won six (6) ASCE awards, including two (2) Hilgard Hydraulic Prizes in 1971 and 1973, and a Stevens Award in 1973. The Boston Society of Civil Engineers has honored him with three (3) awards with the latest being in 1990, and he has received two (2) awards from the College of Engineering at Penn State as Outstanding Alumnus in 1979 and as an Alumni Fellow in 1987. He has served as a member of the Board of Editors of the international *Journal of Hydraulic Research*, and was a member and Chairman of the Executive Committee of the Hydraulics Division of ASCE in the 1960's. He has spent residence time overseas as a visiting engineer at the Delft Hydraulics Laboratory in the Netherlands and at the International Institute for Applied Systems Analysis in Austria, as well as being a Guggenheim Fellow in the Department of Applied Mathematics and Theoretical Physics at the University of Cambridge, England. He gave the First Hunter Rouse Hydraulic Engineering Lecture for ASCE in 1980.

For ten (10) years beginning in 1973, Don Harleman was the Director of the Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics. During that same period, he was the Head of the Water Resources and Environmental Engineering Division of MIT's Department of Civil Engineering. He has a very extensive record of research, publications, and consulting on a national and international level. His current consulting takes him occasionally to Mexico, Hong Kong, Italy, and Brazil.

Don Harleman is a co-holder of two U.S. patents in hydraulics and environmental engineering. He is the co-author of the 1968 textbook *Fluid Dynamics*, and also the author of "Stratified Flow" in Streeter's 1960 *Handbook of Fluid Dynamics*. The Donald and Martha Harleman Professorship at MIT was established in 2000 through an endowment raised by his friends and former students.

SAVING VENICE FROM THE SEA

Dr. Donald R. F. Harleman

ABSTRACT

The survival and prosperity of Venice, built on more than a hundred small islands in the middle of a large lagoon at the head of the Adriatic, during its thousand year history has been achieved by the solution of a succession of engineering "problems".

The **first** problem was the physical conservation of the lagoon. Venice was never successfully invaded because the one meter average depth was too deep for armies and too shallow for navies. The lagoon was protected from silting several hundred years ago by diverting the three major rivers outside the lagoon.

The **second** problem was the protection from Adriatic storm waves of the thin sandy barrier on the ocean side of the lagoon. After diversion of the rivers, sediment transported from the lagoon through the three openings was insufficient to prevent erosion of the barrier. By the 18th century, construction of groins had stabilized the fragile barrier.

The **third** problem was a result of pumping ground water in the mainland industrial area in the 1950s. By 1975, Venice had subsided about 12 cm and pumping was stopped. This is equivalent to 300 years of natural subsidence.

The **fourth** problem is caused by global warming and accelerating sea level rise. Venice is the most sensitive place on earth to the impact of centimeters of tidal elevation change. Due to the combined effect of sinking and sea level rise, tides are 25 cm higher than a 100 years ago. Therefore there are more frequent floods and an increase in economic dislocation and structural damage. A predicted sea level rise of 50 cm in the next 50 to 100 years means that the City would become uninhabitable.

Following the disastrous flood of 1966 in which all of Venice was under a meter of water for 15 hours, the Consorzio Venezia Nuova (CVN) was formed and charged with protecting the city.

CVN's proposed Venice gates are unique in that they are raised and lowered by buoyancy. Each gate module is a hollow steel box 20 m wide and long. A total of 80 gates are needed to close the three barrier openings. Normally the gates, filled with water rest horizontally on the bottom and are hinged at the seaward end. They can be raised by expelling the water by compressed air thereby causing the gates to rotate upward to an angle of 45º.

From the early days of planning for the protection of Venice against flooding there has been a vocal opposition to the movable gates by those who insist that more passive defenses are possible. These include permanently narrowing the width and depth of the 3 inlets and raising the level of pavements in the city—however, repeated studies have shown that these interventions cannot protect Venice against the increasing number of storm tide flooding events.

In 1996 CVN appointed an International Panel (of which I am a member) to oversee the development of an Environmental Impact Assessment for the movable gates. The Panel also strongly recommended the gates as the only viable solution. Construction cost is estimated at about 3 billion euros and construction time at 8 years.

Ultimately the Venice flood gates will have to be built, as they have been in the Netherlands and London. The Italian government has recently completed the stabilization of the foundation of the leaning tower of Pisa—Venice is incomparably more important and deserves no less.

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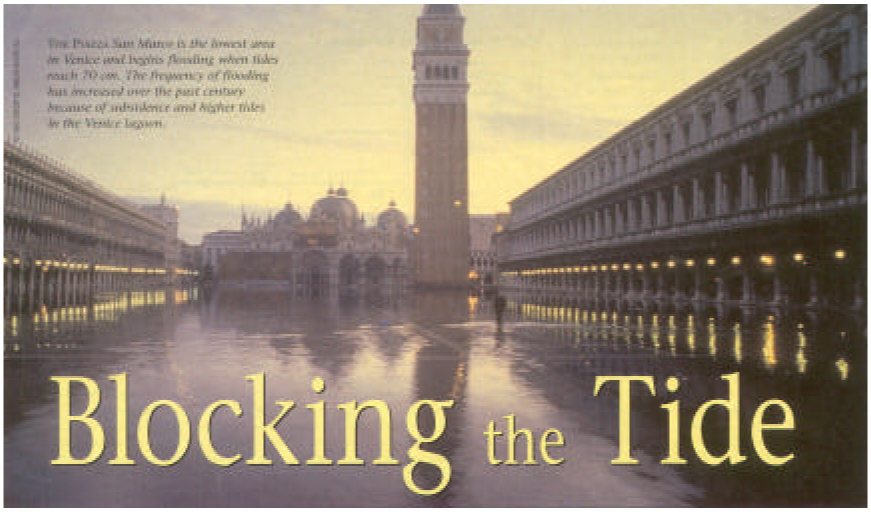
The following article is relevant to the lecture.

"Blocking the Tide" was written by D. R. F. Harleman, R. L. Bras, A. Rinaldo and P. Malanotte, and published in *Civil Engineering*, October 2000. Permission to reproduce the article was granted by the publisher, ASCE, and Dr. Harleman. All photographs by Consorzio Venezia Nuova.



by

Donald R. F. Harleman, Rafael L. Bras, Andrea Rinaldo, and Paola Malanotte

The Republic of Venice existed from about the 8th century to the end of the 18th, when the last doge surrendered the city to Napoleon. The survival and prosperity of Venice—a collection of hundreds of small islands in the middle of a large lagoon at the head of the Adriatic—during its thousand-year history have been achieved by the solution of a succession of engineering "problems."

The first problem faced by the early civic leaders was the physical conservation of the lagoon, which guaranteed that Venice could continue to defend itself by maintaining its "surround" of shallow water. Venice was never successfully invaded because the average depth of the lagoon, 1 m, was too deep for armies and too shallow for naval vessels. The lagoon had to be protected against silting from the sediment transported by rivers. The problem was solved starting in the early 1300s by diverting the three major rivers flowing into the lagoon. This large and successful hydraulic engineering operation ended in 1860 with the diversion of the Brenta River to an area south of the lagoon.

The second problem was a consequence of the solution to the first. The lagoon of Venice is separated from the Adriatic by a long, thin, sandy littoral barrier. Following the diversion of the rivers, it was found that sediment previously transported out of the lagoon through the three barrier openings and deposited by the littoral currents was insufficient to prevent a net erosion of the barrier by waves. By the middle of the 18th century construction of the ocean-side protection, consisting of groins and large blocks of stone, stabilized the fragile parts of the littoral.

The third problem was related to the growing use of Venice as a commercial port. In the 20th century the increase in the draft of ships required deepening of the three barrier openings and the construction of long parellel jetties to maintain the inlet depth. In addition, deeper navigation channels had to be dredged within the lagoon to provide access to mainland dock facilities. This has affected the sediment balance and resulted in a more rapid response of water elevations in the lagoon to storm tides.

The fourth problem was a result of the enormous demand for fresh groundwater coincident with the development of an industrial area adjacent to the port after World War II. Between 1945 and the late 1970s Venice subsided a total of 11 cm. When it was realized what was happening, the pumping was stopped. This rapid subsidence was equivalent to about 300 years of natural subsidence.

The fifth problem is related to global warming and accelerating sea level rise. Its potential effect on the survival of Venice in the next 50 to 100 years is greater than all of the earlier problems combined. Mounting damage by the increased height and frequency of tidal flooding of Venice caused by subsidence and sea level rise (in Italian, *acque* alte) has progressed to the point where engineering solutions must be found.

Venice is the most sensitive place on earth in terms of the effect of a few centimeters of tidal elevation change. The average astronomical tidal amplitude in Venice is about 65 cm above the current mean sea level datum. The Piazza San Marco—Saint Mark's plaza—the lowest point in the city and the site receiving the greatest number of visitors, begins to flood by backflow from the sea through its storm drains when the tide reaches 70 cm. This is below the elevation of a typical "spring" astronomical tide without any additional rise caused by meteorological events. The great storm of November 3-4, 1966, resulted in record tidal level of 194 cm and more than 120 cm of water in the Piazza San Marco. The entire city was flooded for a period of 15 hours. The modern history of dealing with *acque alte* in Venice dates from this catastrophic event. The number of floods per year above 80 cm has grown from about 20 in the 1950s to about 50 at present. In 1996 there were 100 such events, including 7 storms in which the tidal level was greater than 110 cm and 2 greater than 130 cm. The result has been a significant increase in economic dislocation and structural damage to the ancient fabric of the city. We estimate that the most probable sea level rise in the area over the nest 100 years will be 30 cm. This is less than the Intergovernmental Panel on Climate Change's most probable estimate of 50 cm average sea level rise. Nevertheless, a rise of 30 cm or more would mean that the Piazza San Marco would be under water almost every day during the flooding season—generally around November—unless something is done.


THE PORTICO of the Doge's Palace has suffered long-term damage from repeated flooding.

During the 1970s a number of commissions were set up and studies undertaken to consider means of protecting Venice; however there was no clear assignment of authority. It was not until 1984 that a special national law formed two important organizations: the Comitatone, an interministerial steering committee chaired by the prime minister, and an independent concessionaire reporting to the Magistrato alle Acque, an ancient Venetian office responsible to the Ministry of Public Works. This second agency, known as the Consorzio Venezia Nuova (CVN), was formed from about 50 of the largest public and private civil engineering and construction firms in Italy.

The charge to the CVN is far reaching: It has responsibility for planning, testing, and carrying out public works aimed at restoring the hydrological and morphological balance and halting and reversing the process of decay in the lagoon. Of greatest importance is its responsibility for protecting the city against the exceptionally high tides that are causing floods and damage with increasing frequency.

In 1989 the CVN submitted its first outline of a general program, including movable gates at the three inlets, for safeguarding Venice and the lagoon. Several important criteria were incorporated into these plans to ensure that in the process of protecting the city the delicate balance of the lagoon's environment would be maintained: The proposed works were not to degrade the lagoon water quality by reducing the exchange of water between the lagoon and the open sea; they were not to pose an obstacle to navigation; and they were not to alter the aesthetics of the seascape. This meant that the three inlets could not be permanently narrowed by fixed structures and that movable gates capable of being closed to prevent damaging tides could not be visible or present a hazard to shipping when not in use. In this respect the movable gates in

Venice will be very different from those already built in the Rhine and Schelde estuaries in the Netherlands and the flood barrier in London on the Thames. The proposed Venice gates are unique in that they are raised and lowered by buoyancy. According to the preliminary design, each gate module consists of a parallelepiped steel caisson 20 m wide and between 20 and 30 m long depending on the depth of the inlet. The gate modules are hollow with internal steel bracing; their thickness is between 3 and 5 m and in weight they range from 200 to more than 300 Mg. The gates will be prefabricated in dry docks from which they can be floated to their location and set into position by a crane. The middle and southern inlets, at Malamocco and Chioggia, are each 400 m wide and have 20 gates each. The wider inlet at Lido has two sets of 20 gates separated by an artificial island in the middle. Inlet depths for navigation vary from 15 m at Malamocco, which serves the port of Venice, to 6 m at the Lido opening in the north.

In its open position the gate module is filled with water and rests horizontally in a recess in a concrete foundation structure. Each gate is connected to the foundation structure by a horizontal hinge at its seaward end. The gates can be raised in about half an hour by introducing compressed air, expelling water, and causing the gate to rotate upward on its hinge to an angle of 40 to 50 degrees to the horizontal. Each gate is independent of its neighbor and is free to oscillate slightly in response to seaward wave motion. In their open position the gates can maintain an elevation difference of up to 2.5 m between the sea and the lagoon. The most critical element of the gate design is the hinge connector. This unit must allow for gate rotation, the passage of compressed air, and connections to detect the gate angle, and it must also be able to anchor and disconnect each gate module. In this way a single damaged gate can be removed from its foundation structure for repair or maintenance without the aid of divers. A gantry crane, normally housed in the land-side abutment, can be moved out on rails and a gate can be replaced by a spare within eight hours.

The gates are supported in prefabricated foundation structures of reinforced concrete placed in excavated trenches about 10 m deep. The geotechnical conditions at the inlets consist of alternating layers of cohesive and sandy soils, and it is thought that pile supports of the foundations will not be necessary because of the weight of the excavated material and that of the foundation structures are about the same. Watertight seals are provided between adjacent units to accommodate continuous lateral service tunnels.

From the early days of planning for the protection of Venice against flooding there has been vocal opposition to movable gates by individuals and groups who insist that other, more passive defenses are possible. These so-called diffuse interventions (*interventi diffusi*) are aimed at, first, increasing the resistance to the penetration of tide into the lagoon by reducing the depth and width or increasing the roughness of the inlets, changing the configuration of deep channels within the lagoon leading to the port of Marghera, or changing the orientation of inlet breakwaters. Second, the measures involve increasing the tidal volume within the lagoon by opening fish farms and other areas confined by dikes near the land boundary. These proposed solutions have been studied and modeled in great detail by the CVN, and the conclusion, which is supported by independent reviewers, is that none of the "diffuse interventions," singly or in combination, would be effective in reducing the lagoon elevation caused by major storm tides. Furthermore their cost, both monetarily and in the effect on navigation and the environment, would be very high.

Location of Mobile Flood Barriers

In 1990 the Ministry of Public Works, seeking to counter increasing opposition from the port of Venice because of the effect of gate closures on shipping, directed that the gates be put "on hold." The idea was to consider raising the elevation of the perimeter of the many small islands (*insulae*) that are subject to flooding at elevations above 80 cm. Extensive studies have shown that it is feasible to raise local perimeter elevations to prevent flooding to 100 cm. This work has entailed elevating paved surfaces and seawalls surrounding the islands and canal banks, and except for the Piazza San Marco it is now largely completed. The movable gates will be closed only when tides greater than 100 cm are forecast, and this will reduce the number of closures and the effect on navigation. Under present sea level conditions the gates would be closed 5 to 10 times per year. There are efforts to continue the general *insulae* protection to elevations above 110 cm, but the costs and the effect on architectural integrity and functionality—for example, short and depressed entrances—are deemed unacceptable.

The Ministry of Public Works also stipulated that the gate project should await the completion of the lagoon cleanup. By 1990 the summertime water quality of the lagoon had reached crisis proportions, with fish kills associated with vast floating mats of algae and concomitant odors. The blooms of algae are caused by an overabundance of pollutants and nutrients entering the lagoon from the city (Venice not having sewage treatment), the port, and surrounding towns, as well as by the runoff of agricultural fertilizer from the watershed. There was no mention, however, of what indicator would be used to signal the completion of the cleanup. Ultimately the Comitatone voted to move on with the CVN's general plan, subject to a reconsideration of alternatives to the gates and attention to lagoon water quality. Since 1990 the lagoon water quality has improved, largely through the construction of municipal and industrial treatment plants, which have reduced nutrient inputs.

The history of efforts to solve the problem of the flooding of Venice since the great flood of 1966 shows the increasing political and technical tensions that have repeatedly thwarted any solution. In the early 1990s the CVN, together with its consultants and associated research organizations, refined the design of the movable gates. For example, the gate design was subjected to extensive theoretical and hydraulic model studies to investigate the possibility of an interaction between the periodicity of the sea waves and the natural frequency of vibration of the gate module leading to excessive angular motion and large hinge forces. To avoid this problem, the gate frequency was changed by adjusting the mass of the gate.

The seeds of the growing conflict between the city of Venice and the CVN were sown in 1988 when a group of intellectuals that included M. Cacciari, a professor at the University of Venice, referred to the CVN as "the de facto single planning body" whose choices could be questioned by no other organization. Cacciari became mayor of Venice in 1993 and served in that post until the spring of 2000. From the beginning he questioned the CVN studies and conclusions regarding the ineffectiveness of the "diffuse interventions" in reducing high tides. In addition he appears to believe that the gates will not be necessary.

In 1991 a meeting of the Organization for Economic Cooperation and Development (OECD) held in Venice launched an appeal to the Italian government to stop the political bickering and to take immediate action to save Venice. There was even discussion of whether Venice should be accorded "special status" under the protection of the European Union. This was vigorously opposed by the mayor and others.

In September 1994 the president of the CVN wrote to the prime minister informing him that "while Venice's problems are getting worse," the players concerned are "in denial" about the major issues. In October of that year the Comitatone gave a green light to the execution of the gate project. The administration of he city of Venice was very critical of this move, and in March 1995, acting on the basis of findings of a technical working group appointed by the mayor, it proposed that the project be stopped until it could be subjected to a full environmental impact assessment. This was accepted by the Comitatone in July. The political complexity is described by S. Amorosino in his book *Safeguarding Venice* (1996): "The lagoon of Venice is not only a landscape and environmental system of exceptional importance, but also a place with one of the highest concentrations of powers and administrative interventions in the world, producing enormous institutional complication."

A new era in the saga of saving Venice began in July 1995 when the Comitatone voted to subject the movable gates project to an environmental impact study (EIS). In March 1996 the CVN received the necessary authorizations to engage consultants to prepare the EIS. At the same time an independent international panel of experts composed of faculty from the Massachusetts Institute of Technology, the University of Padua, and an international firm, A.D. Little, based in Cambridge, Massachusetts, was established to oversee the work of

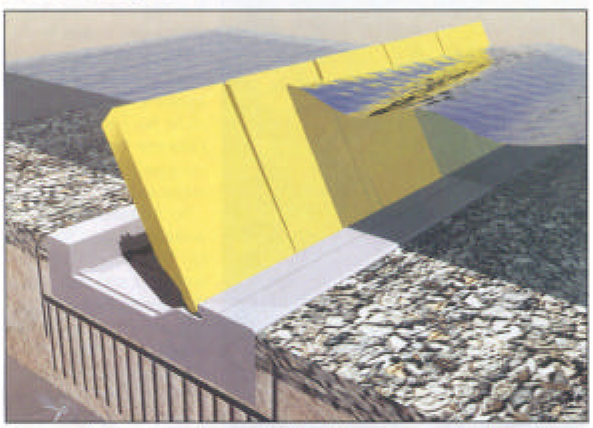
THE LAGOON *of Venice covers about 550 km². The tides of the upper Adriatic Sea have a normal amplitude of 60 cm.*

the consultants in the development of the EIS. (We were members of that panel.) The completed EIS was delivered to the appropriate government agencies in May 1997.

The panel concluded that under constraints imposed by existing laws the only viable solution to the problem of flooding consisted in the proposed movable gates. Is also found that the project had benefited from excellent engineering and thorough conceptualization. The “diffuse interventions” were not by themselves seen as capable of solving the flooding problem—and some, the panel warned, might prove damaging to the environment. Furthermore the panel believed that history and sound scientific evidence made a continued rise in the sea level the most probable scenario. Even scenarios foreseeing only modest sea level rises, it noted, involve persistent and catastrophic flooding in the lagoon and the city of Venice. The panel believed that the project in question was justified under present conditions and furthermore that the city and the lagoon could not afford to “wait and see” whether the sea level would continue to rise and flooding would worsen.

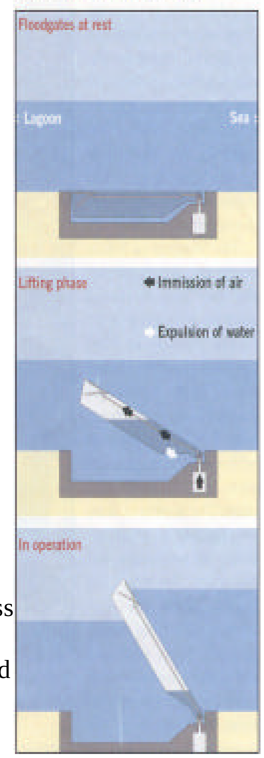
The EIS addressed the effect on the lagoon water quality of increasingly frequent gate closures under future sea level rise scenarios. It concluded that the movable gates can be operated in a way that benefits the ecosystem. In the absence of flooding, circulation in the lagoon can be increased by operating the three sets of gates with different opening and closing patterns. It is worth noting that years ago the esteemed oceanographer Walter Munk pointed out that the gates could be used to increase lagoon circulation by proper management and differential closures. This benefit, however, in no way diminishes the need to continue efforts to reduce the eutrophication in the lagoon by controlling the volume of nitrogen and other pollutants from non-point-source drainage basins as well as the entry of untreated waste from the city itself.

Raised Floodgate



THE GATES fill with water under normal tidal conditions and rest on the inlet canal bed. When tides reach 100 cm, the gates will be filled with compressed air and rise to isolate the lagoon from the sea.

Floodgate Movement



The assessment of the movable gates on the basis of a rigorous cost-benefit analysis would be highly complex, if not impossible, because the city’s intangible artistic, cultural, and historical aspects do not lend themselves to quantification. Nevertheless an approximate socioeconomic analysis has been carried out as part of the EIS. The short– and long-term costs of the principle project alternatives, as well as the avoided costs—that is, benefits—resulting from implementing the movable barriers, were discussed.

The panel concluded that the city and the lagoon region have many significant problems other than flooding that must be dealt with: the economic viability of the entire area, the protection of the lagoon ecosystem and its water quality, and the rehabilitation of the housing stock and transportation system. None of these problems can be effectively and efficiently addressed without a means to control the inevitable increased flood magnitudes and frequency. The construction of the movable barriers should serve as an impetus for the city and regional leadership to deal with all the issues. The effectiveness of he movable barriers in flood control should be exploited as a way of attracting funds to deal with the other vital problems of Venice.

The submission of the EIS increased the antagonism between the various parties. For example, the mayor appointed his own local committee to review the EIS and organized an open “debate” between his committee and the CVN in March 1998. The meeting was highly confrontational, his group focusing on objections to details of the EIS methodology and the CVN group discussing design features of the plan and the need for a prompt solution to the flooding problem.

PEDESTRIAN WALKWAYS *in the Tolentini area were flooded often until a construction program begun in 1997 started to raise levees and pavements.*

An international committee appointed by the Comitatone also reviewed the EIS, and its report, issued in June 1998, agreed with the conclusions of the EIS. The project was also endorsed by the Ministry of Public Works, the region of the Veneto, and the European parliament. In December 1998 the minister of the environment, following a review of the EIS, refused to accept the EIS and released a new report that in essence ignored the basic need to protect the city against flooding and justified the rejection by vague statements about the “natural harmony” of the lagoon and the preservation of its “ecological equilibrium.” Consequently in March 1999 the Comitatone again delayed a decision on the Venice project and called for another study of the tidal forecasting system, the “diffuse interventions,” and the feasibility of raising *insulae* to levels above 100 cm. This report was submitted by the CVN at the end of 1999. However, before any action could be taken the prime minister resigned, and the various cabinet ministers—whose views on this issue varied—were replaced.

There is no indication that the cost of protecting Venice by movable gates is a major issue in the stalemate. It is estimated that the project will cost between $2.5 billion and $3 billion and that construction will take eight years.

The latest event in this drama of political infighting and indecision was precipitated by the provincial government of the Veneto (the region in which Venice is located), which had appealed to the Supreme Court to nullify the December 1998 rejection of the EIS. In June 2000 the court ruled in favor of the Veneto. It appears that action to save Venice may finally be under way.

It is unfortunate that recent articles published in prominent American publications have disseminated misleading information about and suggested an impractical solution to the problem of flooding in Venice. These articles suggested that “new data” on the long-term rate of rise in relative sea level in Venice are raising questions about the feasibility of the movable gates. They also suggested that the high frequency of gate closings will disrupt the ecological balance of the lagoon by cutting the lagoon off from the cleansing currents of the Adriatic Sea. And the solution proposed was that Venice be rebuilt at a higher level—that sidewalks, canal walls, and even buildings be elevated.

Archaeological excavations are cited as the basis of the “new data,” but in fact there are no new data. The archaeological studies revealed that relative sea level has been rising in Venice for a very long time and that the future portends more relative sea level rises, which will accelerate the devastating frequency and magnitude of floods in the lagoon of Venice. That information is nothing new. The EIS and the design for the movable gates take into account every aspect of predicted sea rise, as discussed previously.

With respect to concerns raised about the impact of gate closures on the water quality and ecology of the lagoon, the issue would not be so much about water quality and ecological impact as about the interruption of the navigation of large ships during flooding season. The water quality and ecological problems of the lagoon—now and in the future—will be resolved only by proper management of waste inputs (including sewers to collect the raw wastewater of Venice), not by making the city choose between drowning in dirty water and drowning in water that is slightly cleaner.

Finally, it is not possible to build up the city of Venice and the rest of the lagoon infrastructure to protect it against a flood like the one that made the Piazza San Marco a 1.2 m deep lake in 1966. Such an effort would be impossible technically and financially and unacceptable from both historical and architectural perspectives.

Another recent news article reported that by “elegantly combining state-of-the-art technology and simple mechanics, engineers have succeeded in halting the earthward tilt of the Leaning Tower of Pisa and are pulling it back just enough to give the Tuscan icon a few more centuries of stable existence.” Venice deserves no less.

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Donald R. F. Harleman, Ph.D., is the Ford Professor of Environmental Engneering, emeritus, in the Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology (MIT); Rafael L. Bras, Ph.D., is the Bacardi and Stockholm Foundations Professor and head of the Department of Civil and Environmental Engineering at MIT; Andrea Rinaldo, Ph.D., is a professor of civil engineering in Italy in the G. Poleni Institute of Hydraulics at the University of Padua; and Paola Malanotte, Ph.D., is a professor of physical oceanography in the Department of Earth, Atmospheric, and Planetary Sciences at MIT.

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