INTERNATIONAL ASSOCIATION FOR HYDRO-ENVIRONMENT ENGINEERING AND RESEARCH

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THEMED ISSUE: PANAMA CANAL

IAHR AIRH

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A SHARK TOOTH AS A SOUVENIR OF THE PANAMA CANAL

EDITORIAL BY DR. LUCAS E. CALVO G. AND PROF. MICHELE MOSSA

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Mankind crossed the oceans to settle all the continents. Navigation has always been linked to exploration, commercial activities and political affairs. Vikings explored and established colonies around the North Atlantic between AD 1000 and AD 1300. More than 1000 years ago, Polynesians and Micronesians sailed thousands of kilometers across the Pacific to colonize Pacific islands from New Zealand to Hawaii. Chinese ocean voyages extended the influence of the Ming dynasty. European ocean explorations continued in the fifteenth century with Portugal's exploration of the Atlantic. Europeans traded in the Far East for incense, silk and spices, using a combination of sea routes and overland caravan routes across central Asia (the Incense Road, the Silk Route and the Spice Routes are historically well-known).

In the history of navigation, ship canals have been constructed for a number of reasons, for example to create a shortcut and avoid lengthy detours, to create a navigable shipping link between two land-locked seas or lakes, to provide inland cities with a direct shipping link to the sea or to provide an economical alternative to other options.

A ship canal is specifically designed to accommodate ships used on the oceans, seas, rivers or lakes to which it is connected. Ship canals also includes enlarged barge canals, or canalized or channelized rivers. Among the most famous canals is the Suez Canal (with a length of 193 km and a depth of 24 m) which was opened in 1869 to link the Mediterranean Sea to the Red Sea; the Kiel Canal (with a length of 97 km and a lock dimension of 310 m x 42 m x 14 m) which was opened in 1895 to shorten the passage between the North Sea and the Baltic Sea; the White Sea–Baltic Canal (with a length of 227 km and a lock of 135 m x 14.3m x 3.5 m), which was opened in 1933 and is partly a canalized river and partly an artificial canal; the Danube–Black Sea Canal (with a length of 64 km and a lock dimension of 138 m x 16.8 m x 5.5 m) which was opened in 1984 and links the Danube to the Black Sea. It is well-known that some of these canals have a strategic international role in navigation and, therefore, in the political and economic affairs of States, sometimes causing also international crises. In the Suez Canal crisis the Canadian Secretary of State for External Affairs, Lester B. Pearson, proposed the creation of the first United Nations peacekeeping force to ensure access to the Suez Canal for all. For this reason, on November 4th 1956, a majority of nations at the United Nations voted for Pearson's peacekeeping resolution, which mandated the UN peacekeepers to stay in Sinai unless both Egypt and Israel agreed to their withdrawal.

One of the most strategically important ship canals must be the Panama Canal, which was opened one hundred years ago in 1914 and links the Caribbean Sea to the Pacific Ocean, creating a critical shortcut.

Because of the steady increase in world shipping, speculation on new canals continues. The Inter-Oceanic Nicaragua Canal is a proposed waterway through Nicaragua to connect the Caribbean Sea and Atlantic Ocean with the Pacific Ocean. Such a canal would follow rivers up to Lake Nicaragua and then continue at least 10 kilometers through the isthmus of Rivas to reach the Pacific Ocean.

As shown by C. M. Lara, A. L. Lim and J. C. Monroy in their article entitled "The Panama Canal: existing and new locks: same goal, different scales", the Panama Canal is a lock system that raises a ship up 85 feet (26 meters) to the average elevation of the Gatun Lake and then lowers it again to sea level. It has a total of six steps (three upwards and three downwards divided into three set of locks) for a vessels' passage. Tthe construction of the existing Panama Canal locks was started by the French in 1881. However, due to a financial crisis, technical problems and a high rate of disease and mortality, the project failed. It was not until 1904, when the United States took over the project and, a decade later, on August 15th, 1914, the Panama Canal was officially inaugurated, categorized as one of the most difficult engineering projects ever undertaken. For over a decade a vast battalion of workers braved illness and misadventure to carve a 50-mile (80 km) long channel through the Panamanian isthmus to connect the Atlantic and Pacific Oceans. One of the more unique perks of working on the canal, a sort of ultimate souvenir, was a shark tooth. Occasionally canal workers would find one in the dirt dislodged by dynamite, a souvenir from millions of years ago when the two oceans were still connected. Such a lucky canal worker would then mount the tooth and wear it proudly on a black watch fob.

After approximately 90 years of functioning and non-stop service the existing locks became too small for larger (Post-Panamax) vessels (ships bigger than the Panamax, i.e., maximum dimension of ships to be able to pass through the existing Canal), which were built in ever-increasing numbers, leading to a growing demand for larger locks.

The design and bidding process began in 2006 and, after national referendum approval construction started in September 3rd, 2007.

The project is at this time about 70% complete and is expected to start operations in June 2015.

It is important to note that the expansion project not only involves the construction of the new locks, but also includes excavation of new channels for the new locks, widening and deepening of the existing navigation channels (to allow ships with bigger drafts to pass through and to allow two-way traffic), The project also involves raising the maximum operating level of Gatun Lake, and the construction of a number of earth dams. The operation of the Panama Canal involves a variety of other hydro-environmental and educational issues, such as: water resources management, navigation, municipal and industrial use of water, flood control, climate prediction, ecological conservation of bodies of water, energy generation as well as opportunities in professional expertise and academic research.

From this brief note it is clear the strategic importance of the Panama Canal, which still stands as one of the 20th Century's greatest feats of engineering, and its expansion maybe one of the 21th Century's feats.

This is why in this centenary year this issue of Hydrolink is mainly devoted to the Panama Canal!

We hope that you enjoy it.

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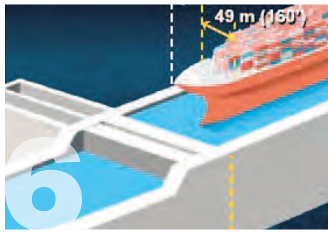
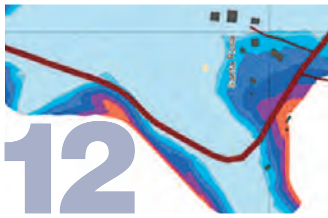




- Panama Canal Authority is an Institute Member of IAHR
- IAHR 2019 World Congress is planned for Panama
- New IAHR Spanish and Portuguese Journal planned for launch in Panama in 2014

IAHR PRESIDENT'S MESSAGE

Prof. Roger A. Falconer
CH2M HILL Professor of Water Management, Cardiff University, UK
IAHR President

Dear Members

At the beginning of the New Year I would first like to send you my very best wishes for the coming year and I hope that the year ahead will be a peaceful, prosperous and healthy one for you and your family.

Last September I was honoured to be re-elected as President of IAHR to July 2015. I am particularly grateful to Professor Nobuyuki Tamai, Nominating Committee Chair (and Past President of IAHR) and his Committee colleagues for nominating me to continue to serve as President for a second term and to the members of IAHR for their support and encouragement. I am also delighted to welcome new elected and co-opted members to the Council and am very grateful to all those serving members whose term had come to an end and who have contributed so much to IAHR during their period on Council. In particular, I am pleased to welcome Professor Arthur Mynett as a new Vice President and am personally very grateful for the support provided to me by the retiring Vice President Jean-Paul Chabard.

Last year's World Congress in Chengdu, China, was extremely successful, attracting over 1500 delegates, (including 400 students) and nearly 1200 papers from 80 countries. For me, personally, it was the Vice Minister (of Water Resources) Dr. Jiao Young's Opening Keynote lecture that was one of the most memorable presentations at the Congress. He talked about how early Chinese civilisation had lived with the river, then managed the river and now realises the need to revert to living with nature. He showed excellent examples of the massive challenges that China faces in managing all aspect of its water resources etc. and these challenges, and the growing importance of water in China, encourage me about the exciting opportunities for IAHR to have a strong base in China, post 2015 which I explain later in this messsage.

The past year has been my second full year in office and a time to continue to build on some exciting new initiatives, focused on addressing some of the challenges our Association faces now, and in the future. In particular, in connection with our new strategic focus, we are aspiring to: (i) implement activities aimed at closer links between academia and practitioners; (ii) develop a Young Professional community; (iii) form closer alliances with other water associations to address some of the global water challenges (e.g. increased flood risk); and (iv) diversify beyond traditional fields and encourage involvement in fields of global concern (e.g. efficient agriculture).

I am delighted to report that our Congresses and other initiatives are leading to a trend of increased membership (now over 3000 Individual Members, which has been complemented by the growing focus on our Regional Divisions for: Asia Pacific, Latin America, Europe, Africa and the Middle East and North Africa. Our Regional Congresses are becoming more prominent within the IAHR technical calendar, as well as delivering excellent networking opportunities - particularly for our younger members. This coming year we have our three important regional congresses, including: the 3rd IAHR Europe Conference in Porto, Portugal (14th -16th April), and the 19th Asia and Pacific Division (APD) Conference in Hanoi, Vietnam (21st – 24th September). I shall be attending the Europe Conference, but regret that I cannot attend the APD Conference as it coincides with my son's wedding. However, I am grateful to IAHR Vice President Arthur Mynett, who will attend on my behalf. Last, but not least, our Latin America Division Congress takes place in Santiago, Chile (25th - 29th August).
I hope that you will try and attend if you reside in one of these regions.

Connecting with Practitioners

In enhancing our links with practitioners we have undertaken two key tasks. Firstly, in Chengdu we launched the first issue of our new Journal of Applied Water Engineering and Research. This new on-line journal is published in collaboration with the World Council of Civil Engineers and by Taylor & Francis; the journal is included in your membership for the first two years. The journal

Meeting Dr. Jiao Yong, Vice Minister of Water Resources, China

From left to right: President Roger Falconer Nobuyuki Tamai, Wolfgang Rodi and Willi Hager and Executive Director Christopher George

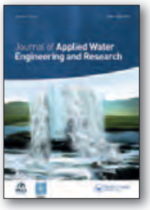
Louise Ellis and Chris Ellis from Arup present details on "Water Sensitive Urban Design" to the IAHR Cardiff Young Professional Network focuses on practice-based research and case studies in water engineering and research, and we particularly welcome papers from practitioners in consulting and specialist modelling companies and government departments and regulatory authorities. The Chief Editor of the journal is Professor Tobias Bleninger, of the University do Parana, Brazil and the Deputy Editor is Teodoro Estrela, of the Jucar River Basin, Spain. For further details see JAWER.

Secondly, we have re-focused Hydrolink, which is our main magazine for all members, published quarterly, and our key opportunity to appeal to new members. The magazine was re-launched in 2013, with about 70% of each issue now focusing on a particular theme or project. A new Advisory Editorial Board of practitioners has been appointed, under the chairmanship of Dr. Angelos Findakakis, of Bechtel, and including representatives from some of our key Institute Members. The magazine continues to be edited by Professor Michele Mossa, of the Technical University of Bari, Italy, and I am very grateful to Michele and the Advisory Board for all they have achieved in transforming this magazine. I hope that you welcome this new focus and please advise either myself or the Editorial team if you have any comments or suggestions for future topics or projects etc.

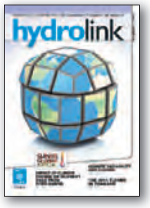
Scholastic Activities

I am delighted with our continuing scholastic activities and was pleased that we published a new IAHR Monograph in 2013 on Large Eddy Simulation, co-authored by Wolfgang Rodi, George Constantinescu and Thorsten Stoesser. I was also particularly pleased to award Honorary Membership of IAHR, at the World Congress in Chengdu, to Professor Wolfgang Rodi, as well as Professor Nobuyuki Tamai (Past President) and Professor Willi Hager (Past Editor of JHR).

The Journal of Hydraulic Research - our flagship journal - continues to flourish under the editorship of Prof. Vlad Nikora, supported by his wife Nina and a strong editorial team. Although the Impact Factor may not have risen as much as we might all have liked over the past couple of years, this journal has a peer review rigor which is second to none. From my own experience with the UK Research Assessment Exercise, this rigor is paramount and the journal is regarded within the UK as being one of the very best in the field. I would like to express my sincere thanks to Vlad and his team for maintaining the very high standards of this journal and for introducing the highly successful new Vision Papers.



The Journal of River Basin Management is now being led by my colleague Dr. Michaela Bray and we are very grateful to Prof. Paul Bates, of the University of Bristol, for all his hard work as the Founding Editor in Chief of the journal until August 2013. Closer collaboration with the IAHS in running this journal is now being developed, with Christopher George and I having recently met with the new President of IAHS, Prof. Hubert Savenije. We agreed that we would run this journal much more as a joint effort in future, with a new editorial board, including more members from the IAHS fraternity. In particular, Prof. Thorsten Wagner, a Vice President of IAHS, is now serving on the executive editorial team (along with myself), and we are confident that the journal will flourish, along with links with IAHS, in the future. Once again, I am grateful to Michaela for agreeing to develop this journal with Taylor and Francis, and we hope that it will have an Impact Factor shortly.



Young Professionals

I am particularly enthusiastic about the IAHR developments relating to the Young Professional Network, being led by Vice President Marian Muste and his team. We have recently re-organised our Student Chapter at Cardiff University to become an IAHR Young Professional Network. This new network has many advantages over the Student Chapter. Firstly, it includes all members within our research team, i.e. research students, post-doctorate research associates under 35 etc. Secondly, the Network also includes young graduate engineers from consulting companies, including Arup amd CH2M HILL at this stage, but with more companies to be recruited. This latter benefit brings our researchers into contact with industrial companies and likewise it gives the companies an opportunity to meet and develop a friendship with our students. I am grateful to my research students and staff at Cardiff University for developing our Network, led by Dr. Reza Ahmadian as the academic link, and I look forward to seeing more networks developed over the coming years and, yet again, more opportunities to engage with companies.

The Future

Finally, as you may be aware our original agreement with our host organisation CEDEX in Madrid, Spain, is due to expire at the end of 2014 and the Executive Committee has been working hard to find a new base for IAHR. Over the past year we have had two attractive offers from (i) the Institute of Water Resources and Hydropower Research, in Beijing; and, more recently, (ii) a public-private joint initiative in Spain, which would retain our links with CEDEX. I am delighted to report that our Council has approved that as of the end of 2014 onwards IAHR will have two head offices of equal standing, but different responsibilities. These include offices in Madrid and Beijing. This is an exciting opportunity for IAHR's future and will enable us to provide a better service to our members and take on board new initiatives with the additional resources. The distribution of the workload between the two offices is currently being arranged through a council team chaired by our Executive Director, Dr. Chris George, but one of the new initiatives being considered is the development of an internationally recognised professional qualification along the lines of Professional Water Engineer and Scientist (PWES). We are hoping that any such qualification will be developed in association with UNESCO, and with assistance from IHE Delft, and we plan to develop this qualification in partnership with other learned societies in the water field. Furthermore, the opportunity of two offices will enable us to work more closely with the organisers of our World and Regional Congresses to a higher standard, as well as exploring the scope for developing our publishing activities etc. and delivering more to our members.

In summary, I believe that these are really exciting times for our association and I am grateful to you all for your support and encouragement. In the meantime, I would like to conclude this message by again extending to you my very best wishes for 2014 and on behalf of IAHR I would like to express my sincere thanks to all those members who have contributed so much of their time to the committees, workshops, journal editorships, books, monographs etc. and to all the staff in the Madrid Office who do such an excellent job with limited resources. Finally, I would also like to express our sincere appreciation to CEDEX (and in particular our dedicated Secretary General, Dr. Ramon Gutierrez-Serret), who provide us with considerable support in terms of monetary and in-kind resources; without their support our fees would have to rise considerably.

THE PANAMA CANAL EXISTIN SAME GOAL, DIFFERENT SCA

BY LARA A. CAROLINA M., LIM CARDENAS ANA LUCÍA, MONROY A. JULIO CÉSAR

The existing Panama Canal locks were designed and built one hundred years ago. Today, due to increasing demand and vessel size, new locks are being constructed to work in parallel with the current locks. Although they share the same purpose, passing ships between the Atlantic and Pacific Ocean, a lot has changed since the existing locks were built. The new and old locks are not only different in size, but also their design and construction differ according to the developments in the fields of material science, construction methods, hydraulic, structural and environmental engineering. This article presents a comparison of the principal characteristics of the existing and new locks, including their dimensions, components, design approach, operation and an overview of the environmental impact studies.

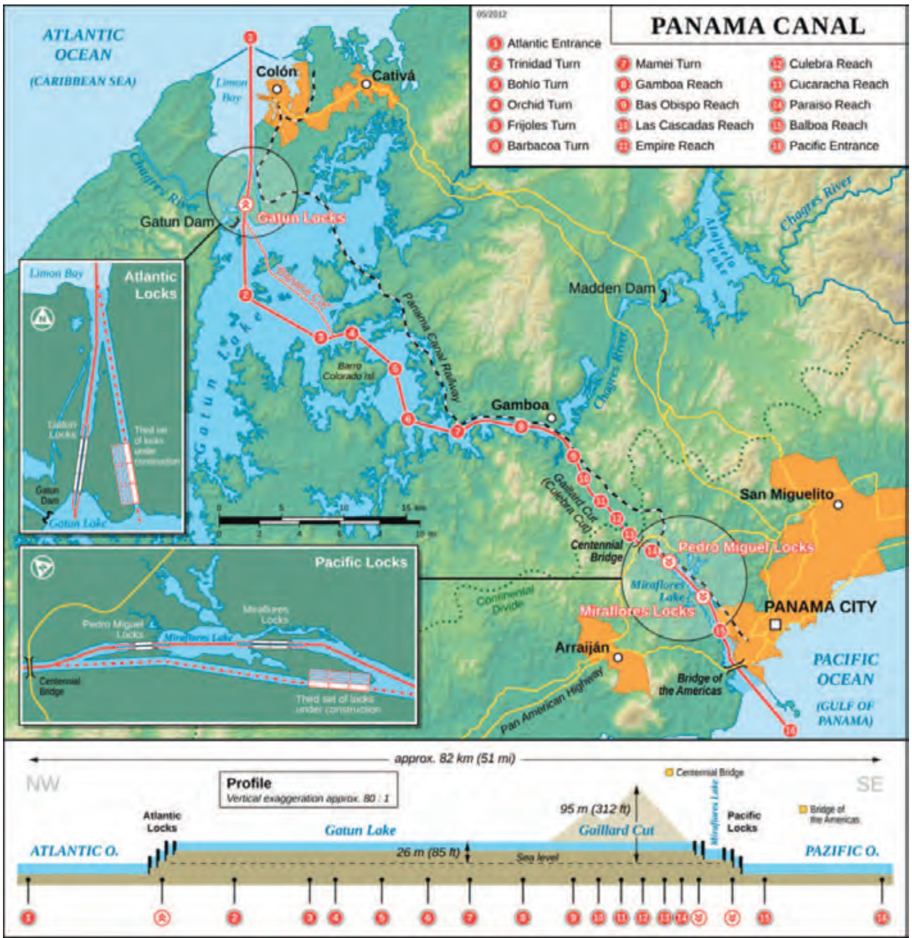


Figure 1: Panama Canal aereal view

The Panama Canal is a lock system that raises a ship up 85 feet to the average elevation of the Gatun Lake and then lowers it again to sea level. It has a total of six steps; three up and three down divided into three set of locks. After approximately 90 years of non-stop service, the existing locks became too small for the Post-Panamax vessels, which number of units started increasing at that time. This is when the need for a new, wider and larger set of locks arose. The design and bid processes for the new set of locks began in 2006 and construction started in September 3rd, 2007. Today, the project is approximately 65% advanced and it is expected to start operations in June 2015.

The expansion project includes the construction of new locks, excavation of new approach channels for these new locks, widening and deepening of the existing navigation channel (to allow a two-way traffic and allow ships with bigger drafts to pass through, respectively), raising the maximum operating level of Gatun Lake, and the construction of a number of earth dams. Figure 1 shows the path of the navigation channel, the location of the existing locks and a render of the proposed site of the new locks.

Components

The existing structure consists of three sets of locks with two lanes each; Miraflores Locks, with two steps; Pedro Miguel Locks, with one

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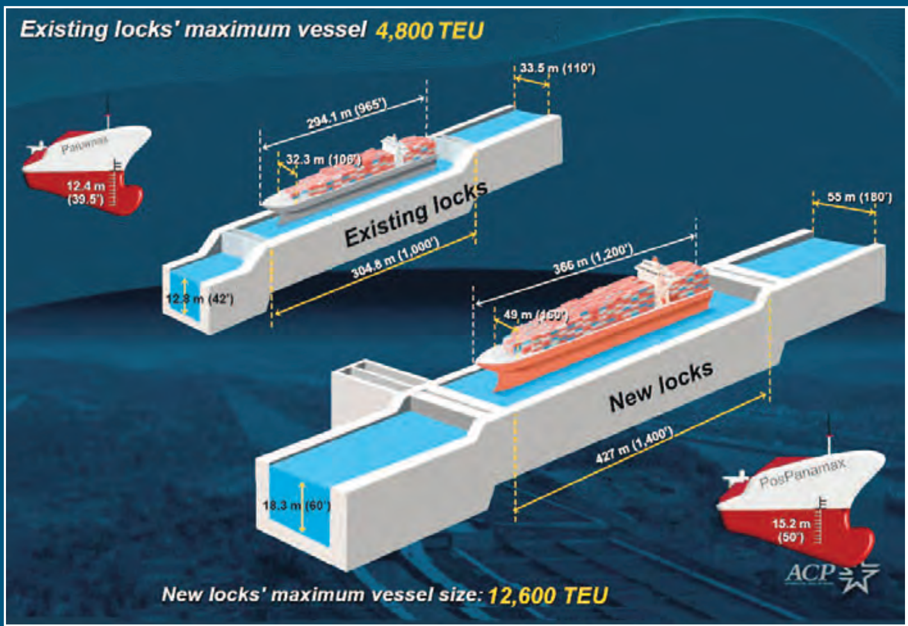
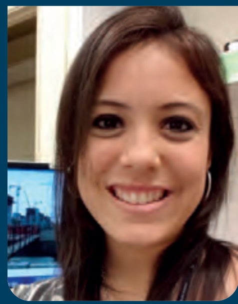


Figure 2: Dimensions of existing and new locks

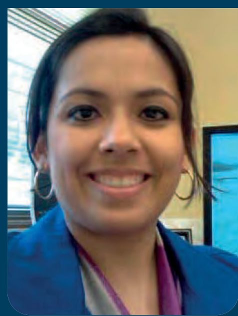
step and Gatun Locks, with three steps. It was decided to build two lanes to have redundancy when maintenance or repair took place and to provide transport in both directions at the same time. Each chamber is 33.5 m wide and 320 m long. The existing sets of locks are mainly composed by main culverts, auxiliary culverts, portholes, gates and valves.
The new set of locks, however, will consist of two sets of locks, one lane in the Pacific side and one lane in the Atlantic side, with three chambers each. The new chambers will be 426.7 m long, 54.9 m wide, and up to 18.3 m deep. The new set of locks is essentially composed by main and secondary culverts, central connections, portholes, water saving basins (WSB), trifurcations, and flow dividers from WSB to secondary culverts, gates and valves.

Concrete. The new and old locks differ in the use of reinforced concrete. The existing locks were built using mass concrete with no rebar. By the time the old locks were finished (1914) the methodology for reinforced concrete was being developed and tested. Even the formulation for the Portland cement was a theme of research and discussion at that time. The standard formula for Portland cement was not established by the US Bureau of Standards and the American Society for testing materials until 1917. Four and a half millions of cubic yards of concrete were used.
The new locks are being constructed with reinforced concrete classified in two types: structural concrete and structural marine concrete. The structural marine concrete contains fly ash admixtures to make the concrete cover impermeable to prevent corrosion of the reinforcement by chlorides. In the construction of the new locks 192000 tons of steel are being used.

Walls. The main walls of the existing locks have a concrete gravity section that ranges in thickness from 14.9 m at the base to 3 m at the top and are 24 m high. On the other hand, the walls of the new locks are of reinforced concrete, with a variable width. The walls are 22.5 m thick at the bottom and up to the entire height of the culverts, then the section is abruptly reduced to a width of 8 m, from which it gradually reduces to a width of 2 m at the top of the wall.



Carolina M. Lara A. **has been working at The Panama Canal since 2010 as part of the Hydraulic Engineering Unit of the Engineering Division. She obtained her degree in Civil Engineering at Santa María La Antigua University in Panama. Then she pursued her studies in the University of Illinois at Urbana – Champaign where she earned a Master of Science in Hydraulic Engineering.**



Ana Lucía Lim Cárdenas **has been working in the ACP's Hydraulic Engineering Unit since 2010. She graduated in Civil Engineering at the Technological University of Panama. She acquired her MSc in Hydraulic Engineering and River Basin Development at UNESCO-IHE Institute for Water Education based in Delft, The Netherlands.**

Julio Monroy **works as a Hydraulic Engineer for the Hydraulic Engineering Unit of the Panama Canal Authority. He has a bachelor's degree in Ocean Engineering from Florida Atlantic University (USA) and Master's degree and Ph. D. in Coastal Engineering from Kagoshima University (Japan).**

Culverts. The existing set of locks has main culverts and lateral culverts. There are three main culverts; one central culvert shared between the two lanes, and two side culverts, one for each lane (Figure 3a). The main culvert in the center wall has a horseshoe shape - flat floor and round roof - with a diameter ranging from 5.5 m to 6.7 m, while the main culverts in the side walls have a circular shape with a diameter of 5.5 m. The lateral culverts are located below the chamber floor, having an elliptical cross section, with a maximum height of 1.98 m and a maximum width of 2.44 m.
The new sets of locks have main and secondary rectangular culverts. The main culverts are 8.30 m by 6.50 m while the secondary culverts are 6.50 m by 6.50 m.

Portholes. The portholes in the existing set of locks are circular, with a diameter of 1.2 m, and are located in the chamber floor; in contrast with the rectangular portholes in the new locks, located in the chamber walls, and having a section of 2 m by 2 m.

Gates. The existing locks use massive steel miter gates. The biggest ones reach up to 25 m high, 19.5 m wide and 2.13 m thick in Miraflores locks, next to the Pacific Ocean, where the largest tidal range takes place. The existing gates consist of two leaves that close to a "V" shape with the point upstream, which allows the force of the water to push the ends of the gates together. For maintenance, these gates are removed using big barge mounted cranes and transported to a workshop to be overhauled. The existing lock chambers have intermediate gates, except for the lower Miraflores lock. These gates divide the lock chamber into two shorter ones for smaller vessels and their original purpose was to save water during the dry season, however, this is unlikely to be used in the present due to the current size of ships. A better technology was developed for the new structure. The new locks being built will use rolling gates which will open sideways, sliding perpendicular to the path of ships. These will allow maintenance in situ, without the need to take the gates out to a workshop garage and without interrupting transit, saving money and time. The new gates will also be larger than the actual ones, reaching up to 32.9 m high, 57.6 m wide and 10 m thick. Intermediate gates were not included in the design of the new locks.

Water Saving Basins. Another aspect on which the new set of locks will differ from the existing ones, is that each set of locks will go with nine water saving basins (three per chamber). These gravity-fed basins will be 70 m wide, 426.7 m long and 5.5 m deep, approximately, and will allow reutilizing 60% of the water used in every transit. Thus, the new locks will use 7% less water per transit than the existing locks, even when they are much bigger. This, plus the facts that the maximum water level of the Gatun Lake will be raised 0.46 m and that the navigation channel will be deepened 1.5 m, will permit the expanded canal to function without the need of new reservoirs. Figure 2 shows a cross sectional view of the water saving basins.

Locomotives. One more feature on which the new structure differs from the existing canal is that the existing locks use electric locomotives all along the center and side walls of the canal. Even though forward motion inside the locks is provided by the vessels' own engines, locomotives work as a safety feature and help keep the vessel in the right position, avoiding accidents or collisions. The new structure, however, is designed to use tugs to keep the vessels in the right place.

Operation

During a lockage, water will flow by gravity through culverts and into the chamber in the existing and new set of locks. The flow in the culverts is regulated using a set of valves, which have an extra set for redundancy.
In both sets of locks the filling and emptying (F/E) process occurs in three different paths: lake to lock, lock to lock, or lock to ocean. In addition, due to the existence of the WSBs in the new set of locks another path occurs: WSB to lock. The existing and new locks' F/E system mainly differ in the distribution and complexity of its hydraulic components.
In the current infrastructure, main culverts are situated along the side and center walls of the locks. The main culverts are connected to lateral culverts located below the chamber floor utilized to transport water from the main culverts into the chambers to raise the water on them or vice versa. Specifically, eleven lateral culverts

Figure 1: Cross sectional view of existing and new culverts

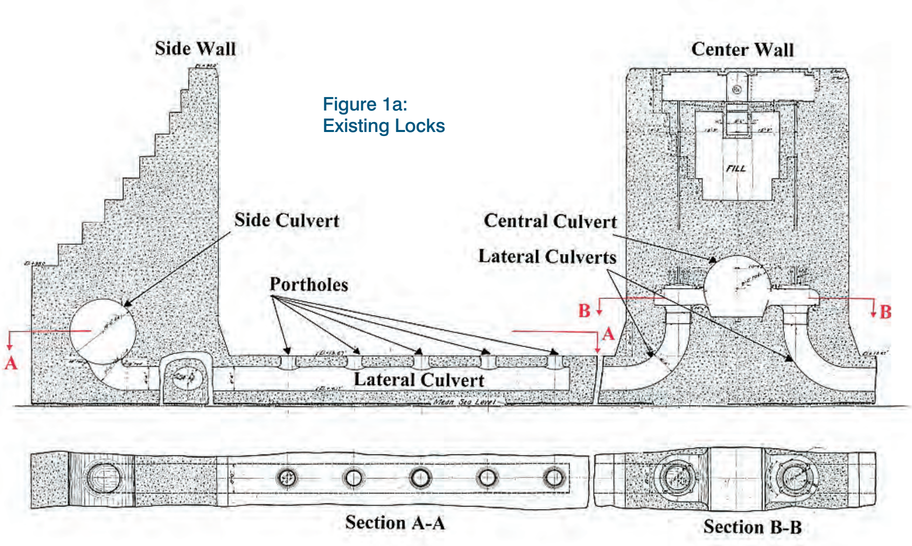
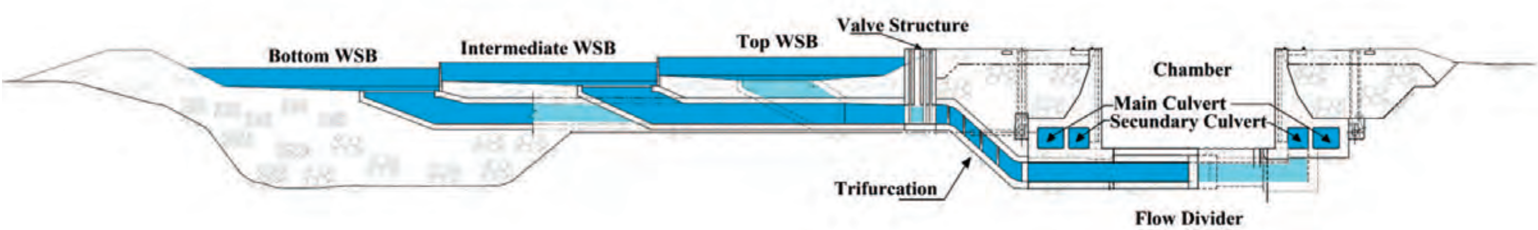


Figure 1b: New Locks



connect the side culverts to the chamber, while ten lateral culverts connect the central culvert to the chamber. In the roof of each lateral culvert there are five portholes, having a total of 105 portholes in each chamber. Water flows from the lateral culvert through the portholes and to the chamber. Each chamber is filled and emptied in a procedure that takes around eight minutes, if the side and central culverts are used. In the whole process, water is moved by gravity and is controlled by huge valves in the culverts. Figure 3a shows a cross-sectional view of the current locks' culverts and floor openings.

The new locks, however, will work with two main and two secondary culverts, all of them rectangular-shaped, to ease its construction (Figure 3b). These will then be connected to 40 rectangular-shaped holes located in the bottom part of the side walls of each chamber, through which the water in the chambers will raise and drain. This culvert configuration will ensure homogenous filling and emptying of the chambers, thus helping in the safety of the operations. The filling and emptying time results were presented in CICP et al (2010) and resulted similar to the values calculated at the tender stage, that is, without WSB ten minutes, and using WSB seventeen minutes.

Every time a ship passes through, the existing Canal uses 55 millions of gallons of water, approximately. Since the new locks will be larger, even more water will be needed to pass ships through, around 63 millions of gallons. Nevertheless, as explained earlier, the water saving basins will allow reutilizing 60% of water per lockage, therefore, the amount of water released to the sea is reduced by 7%.

"the water saving basins will allow reutilizing 60% of water per lockage, therefore, the amount of water released to the sea is reduced by 7%."

Design approach

The existing set of locks was designed using an approximate analytic approach. It had to comply with an acceptable filling and emptying time of 15 minutes (using only one culvert), not producing disturbances in the locks or approach channels. Economy influenced the final dimensions and distribution of the components. For example, it was decided that the culvert located in the central wall was going to operate in both sides of the lock chamber, since constructing an additional culvert would result in considerable higher costs. After finishing the construction of the set of locks, filling and emptying tests were conducted to verify the performance and equalization time of the locks. The tests showed that using the two main culverts (side and central), water distribution was good and also safer and faster (equalizing in around 8 minutes) than using only the side wall culvert. Initially, it was intended to use mainly the side culvert, and the central culvert was only an auxiliary culvert that operated to accelerate the last few feet of flow. The tests also showed that the salinity slightly affected the filling and emptying times and the water distribution in the chambers, mainly in the lower locks next to the oceans.

A numerical and physical modeling approach was used for the new set of locks. Detailed hydraulic studies were presented by the contractor, including the numerical modeling of the filling and emptying system and a physical model of the locks. The results complied with the design requirements: maximum flow velocity of 8 m/s, and for hawser forces a maximum longitudinal and transversal surface slope of 0.14‰ and 0.10‰, respectively. Regarding the numerical models, a one-dimensional model was used to estimate the filling and emptying times and flow velocities. Each component of the new set of locks was individually analyzed to estimate and optimize local head losses using three-dimensional models. Hawser forces were verified using a two-dimensional model of the chambers. The physical model was used to verify and validate the design and the results of the numerical models. A more detailed paper explaining this system is presented by Calvo (2013).

"The tests showed that using the two main culverts (side and central), water distribution was good and also safer and faster".

Water Demand and Environmental Impact

At the time the Panama Canal was built there was little concern about the water resources and the environmental impact of such a project. A major river (Chagres) was dammed, the biggest manmade lake (Gatun) was built, entire villages were displaced, and tops of mountains became islands as the water level rose.

The construction of the Panama Canal had a great impact not only on the environment but also in the way the towns and cities around it developed. The Canal Zone area primarily created for protection and water supply for the canal, became also a wildlife protection area. However, this zone impacted the way Panama City developed as an elongated city near the coast.

The expanded canal will need more water to function. This fact arose some worries on how Panama would manage to get more of this vital resource without causing permanent damage to the environment. During the design process of the Panama Canal expansion project, a comprehensive environmental impact assessment was carried out to make sure that the project did not have unfavorable effects on the environment. During the construction of the new locks an environmental monitoring and control program is in effect to monitor environmental quality, conduct wildlife rescue and enforce mitigation and compensation activities; for example, the reforestation of the Panama Canal watershed. This would help protect the dry-season flows and sequestrate carbon releases, however, it would not necessarily increase water supply. To address this issue, a water supply program was proposed which purpose was to maximize the water capacity of Gatun and Alhajuela Lakes and to use water efficiently so that no communities were affected and no new reservoirs were necessary. This led to the use of the WSB, the deepening of the navigation channel, and the rise of the Gatun Lake; aspects that significantly reduced the impact in water demand.

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WATER RESOURCE MANAGEMENT IN THE PANAMA CANAL

BY JORGE A. ESPINOSA

Historically Panama, due to its narrowness, low level terrain, and location in the middle of the Americas, has been a place of transit between the Atlantic and Pacific Oceans. People and goods have passed from the Pacific Ocean to the Caribbean Sea since pre-Columbian times. During the period of the Spanish conquest, passage from one ocean to the other was made evident when Vasco Nuñez de Balboa discovered the Pacific Ocean on September 25th, 1513. Since those days the idea of building a Canal to expedite commerce between the Pacific Ocean and the Caribbean Sea had been contemplated. This concept was turned into reality by the United States of America with the inaugural transit of the steamer Ancon on August 15th, 1914.

The importance of water for the functioning of the Canal was identified way before its construction. A Frenchman, Adolphe Godin de Lépinay, and his team expressed in the Congrès International d'Etudes du Canal Interocéanique (International Congress for Study of an Interoceanic Canal) that took place in Paris on May 15th, 1879, that a French initiative, promoted by Ferdinand de Lesseps, of constructing a sea level canal was doomed to failure. Lépinay recognized the problems presented by the extraordinary floods of the Chagres River. The theory was that the floods of the Chagres river could only be tamed with a large navigational lake created by damming the Chagres at the Atlantic and the de Rio Grande river in the Pacific. The approximately 80-foot height of the artificial lake, thus created, would be accessed by two sets of locks. The de Lépinay design contained all of the basic elements ultimately incorporated into the current Panama Canal.

The present Panama Canal Watershed (PCW) has a total area of 3338 km^2, and it contains six major rivers: Chagres, Boqueron, Pequeni, Gatun, Trinidad and Ciri Grande. After the construction of Madden dam in 1936, the PCW was divided into two sub-watersheds, the Alhajuela sub-watershed with a surface area of 1026 km^2, upstream of Madden dam, and the downstream Gatun Watershed with a surface area of 2313 km^2, downstream of Madden dam. Due to Panama's tropical climate, with a 9 month rainy season in which rainfall is abundant, the PCW produces an annual average inflow of close to 5000 m^3. Figure 1 shows the boundaries of the Panama Canal Watershed and Figure 2 shows the distribution of the water extracted from the PCW.

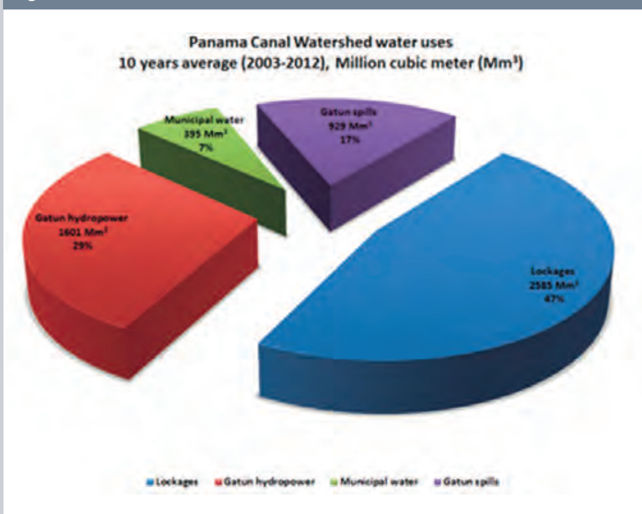
In order to efficiently operate the existing locks, Canal water has to be adequately managed. The Water Resources Section (WRS) of the Panama Canal Authority is the entity responsible for managing the water provided by the rainfall that falls over the Panama Canal watershed. Figure 3 shows the Panama Canal Watershed 20 station average monthly rainfall-histogram, as can be seen November is the rainiest month of the year.

In order of priority water in the Panama Canal is allocated by the WRS to:

1. Guarantee enough crude water for production of potable water for the country's two largest cities, Panama City,

Figure 1: Panama Canal Watershed

Figure 2: Panama Canal Watershed water uses 2003 - 2012



Colon and surroundings areas;

2. Guarantee sufficient water for navigation, the Canal's core business; and
3. Optimize the remaining water, after fulfilling items 1 and 2, for hydroelectric energy production which is sold in the local and Central American markets.

In addition to the above 3 responsibilities, the WRS operates the Panama Canal Flood Control Program. And as owner of the Canal's dams and spillways system, the WRS co-ordinates the maintenance program for these facilities.

To fulfill these responsibilities the WRS has an experienced team of meteorologists, hydrologists and a field workforce which operates and monitors a suite of tools and mathematical models consisting of:

a. A telemetering hydrometeorological network of rainfall, river stage, tide gauge, sea temperature, lake level and meteorological stations at 60 strategically located sites within the Canals watershed and operational area. Figure 4 is a Diagram of the hydrometeorological flow of information and Figure 5 shows the Watershed Map with the telemetering network
b. An S-band Doppler weather radar located on the southern part of the PCW
c. An upper air radiosonde station (WMO 78806)
d. The WRF Meteorological Model
e. A NOAA Port Meteorological data display and analysis system
f. USA National Weather Service River Forecasting System which has the Sacramento model calibrated for the Panama Canal Watershed
g. HEC-RAS model calibrated for the Chagres river between Madden Dam and the Gamboa bridge, next to the Panama Canal's navigational channel.
h. A Decision Support System (DSS) for optimizing the use of water for hydroelectric energy production

The hydrometeorological network requires a well programmed maintenance program which is provided by the Operational Hydrology Unit, of the WRS, with the support of electronic technicians of PCA's Digital Technology Section. Due to remote locations, and the variety of terrain, different modes of transportation are utilized in order to visit all sites of the hydrometeorological network.
Transportation means such as four wheel drive cars, launches, piraguas (dug in canoes), horses, and helicopters are routinely used to service and maintain the network.
Recently, from December 7th - 9th, 2010 the PCW received immense amounts of rainfall on the upper Alhajuela sub-watershed producing the biggest flood since Canal construction days. The management of this storm validated the effectiveness of the Flood Control Program of the WRS of the Panama Canal Authority.
Global warming impact of "the intensification of the hydrological cycle" will pose a tremendous future challenge for the Water Resources Section. The management of the Panama Canal's water, river flows and lake storage volumes all have to be adjusted to take into account the risks of severe drought periods and more intense storms. Signs of this future challenge are starting to become evident.
The PCW, within the last 20 years (1997-2014), has experienced the strongest drought (1997-1998) and the most severe storm ("La Purisima 2010" on December 7-9, 2010) in the history of the canal. This year 2013 has been particularly different with November, normally the wettest month of the year, finishing as the third driest November of the last 100 years in the PCW.

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Figure 3: Bar Graph of 20 rainfall station average monthly rainfall over the Panama Canal Watershed

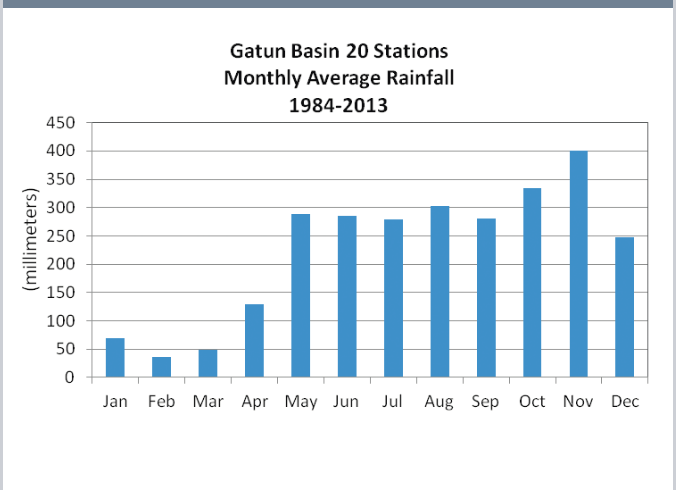
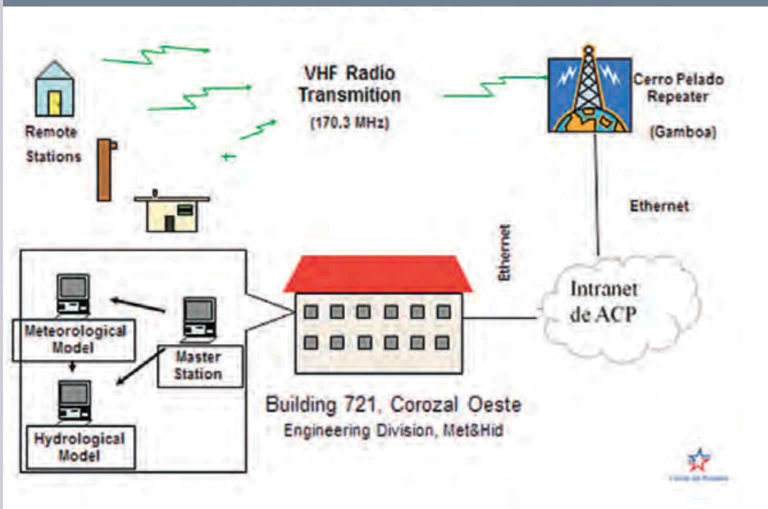


Figure 4: Hydrometerorological telemetry system – Comunication scheme



EMERGENCY RESPONSE PLAN FOR FLOODING IN THE COMMUNITIES OF GUAYABALITO AND SANTA ROSA

BY GERARDO LEIS ROMERO

The Alhajuela reservoir is important to the operation of the Panama Canal,as wellas being an important source of drinking water for Panama City and is used in hydropower generation. Madden spillway to leave the surplus of this reservoir.

Gerardo Leis Romero **is specialized in Meteorology, Surveying, Civil Engineering, Hydraulic and Environmental management system applied. He works as a hydrologist in the Panama Canal Authority since 2001, dedicated to hydrometeorological research, and has been program coordinator for flood control and manage hydrologic and hydraulic models.**

The contributions of water to the reservoir during the rainy season can cause significant increases in water levels. The removal of excess can endanger the lives and property of locals and visitors to the towns of Santa Rosa and Guayabalito located downstream from the Madden spillway.

The Water Resources Section (Water Division) of the Panama Canal Authority with the support of Team Community Relations (Environment Division), and other units and agencies such as the National Civil Protection System (SINAPROC) has implemented actions to minimize risks and train these people. Emergency Response Plan for Flood in the communities Guayabalito and Santa Rosa, includes a description of the risk area, socioeconomic, potential causes of an emergency, flood plain maps detailed list of contacts with communities, arrival times of flood risk reduction plans and evacuation, timetables for action and actions following the flood.

Background

The Water Resources Section of the Panama Canal Authority has run the Flood Control Program since 1972. Risk reduction in the communities of Santa Rosa and Guayabalito, located downstream of the Madden dam has been a major component of this program in recent years.

Figure 1: Regional location of Guayabalito and Santa Rosa

Description of the Risk Area: Guayabalito and Santa Rosa Communities

Guayabalito and Santa Rosa are located in the Province of Colon, Panama limited to the east by the Chagres River in the downstream sector of the Madden Dam. These communities cover an area of 63.79 ha and 7.12 ha respectively, on a stretch of 1.5 km in length, parallel to the right bank of the Chagres River, (Figure 1).
The main asphalt access road is by Boyd - Roosevelt, Nuevo San Juan community. The Chagres River is another means of transport between the communities.
Guayabalito ranges between 26 m and 40 m above sea level bordered on the south by Santa Rosa with elevations ranging from 27 m and 33 m. Guayabalito has slopes between 35-45% in the west highlands and between 8-20% in the east, Santa Rosa has slopes varying between 8 and 25%. A height of 30.48 m is the limit for the operation of the Panama Canal.

The climate is tropical rainforest, with an average temperature between 25° C and 27° C, The average annual rainfall is 2090 mm and the rainy season is from May to December.
The communities are located adjacent to the Chagres River, between 5.7 and 7.7 km downstream of the Madden dam. Depending on the risks of meteorological events water can be released through the Madden spillway to discharge preventive downloads in extreme situations of pre-emergency and emergency. Normal discharges can be up to 2124 m^3/s and in emergency situations to 7079 m^3/s
The population of Santa Rosa is around 162 and is provided with electricity; for rural water a gravity water intake is located in the town of Aguas Claras. The Chagres River is used as transportation, laundry, fishing and bathing.
Guayabalito, like Santa Rosa is located on the west bank of the Chagres River, with a population of some 76 of Afro-Caribbean descent mostly. Economic activities are based on ecotourism,

Figure 2: Aerial view, Santa Rosa and Guayabalito and the Chagres River (2007)

subsistence agriculture (rice, peas, yams, cassava, corn and others); fisheries and service sector jobs (Panama City and Colon).

Flood Maps

In order to estimate the damage caused by discharge from the Madden spillway, a flood plain map was drawn to show the water level in the villages in terms of discharge from Madden spillway. These levels were generated with HEC-RAS (Hydrologic Engineering Centers River Analysis System) then shaped in a topographic map at one meter intervals, raised with surveying instruments. In the village landmarks have been placed indicating the flood plain to the height of 30.48 m reference.

Speed and Time of Arrival Spills

Table 1 shows the arrival time of discharge from the Madden dam which varies according to size and are important for estimating the start time and end the emergency and evacuation plan for residents. Discharges from the Madden spillway may have a time of arrival in the villages about 20 to 30 minutes to download less than 1415 m^3/s and 2 to 4 hours for discharges between 1415 to 2124 m^3/s These results are based on some historical discharges analyzed and recorded of the time of arrival at the Santa Rosa station.

Implementation of Risk, Reduction Plan and Evacuation

The PCA Section of Water Resources with support from the Watershed Management Section - Environment Division - and the National Civil Protection System maintain contacts with these communities through participatory and concerted meetings. Through these meetings the community has been prepared in the following ways:

- Community Diagnosis, 2005
- Characterization of the communities, 2006
- Surveying of the communities: Positioning of signals with elevation 30.48 m (100 ft) contour of housing and infrastructure location and mapping, 2006
- Training workshops to organize and establish the Community Risk Committee, 2006
- Workshop on risk school in the School of Santa Rosa, 2006
- Information for residents on the height 30.48m (100 ft), 2006
- Development Control Plan Flood Risk, 2006
- Validation of community risk management plan, 2006
- Evacuation Exercise, 2006
- Evaluation of the evacuation drill, 2006.
- Community Environmental Management Workshop, 2007
- Signing of a cooperation between the Ministry of Government and Justice through SINAPROC and ACP, 2007
- Workshop plan update flood risk, 2007
- Workshop on flood risk school in the school of Santa Rosa, 2007
- Call and updating database communities, 2008
- Exercise evacuation of people with non-participating observers National Police, SINAPROC, ACP, 2008
- Involvement of community coordinators in the Talk on Flood Control Exercise 2009 at the Training Center Ascanio Arosemena
- Install warning signs in flood risk areas and evacuation routes in September 2009

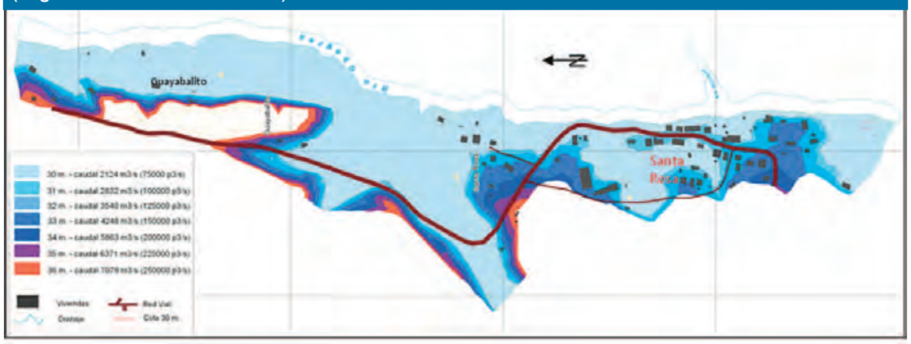
Other Key Components

- Schedule of Community measures to reduce risk
- Preparation of the communities
- Emergency Response Plan, prior to the discharge procedure in madden.
- Base for activating the plan
- Notifications
- Public Warning
- Communications
- Operation of alarms or sirens on Madden Dam
- Actions to take-populations Guayabalito and Santa Rosa
- Warnings and actions
- Duration of the emergency

Table 1: Average elevation of the floodplain as the discharge rate from Madden spillway in the Chagres River, the stretch between Santa Rosa and Guayabalito with HEC-RAS (2009).

Discharge: Madden spillway	m3/s	2124	2832	3540	4248	5663	7079
Average elevation flood plain	m	30	31	32	33	35	36

Figure 3: Map of floodplain to Guayabalito and Santa Rosa for different spills from the Madden spillway (original resolution of one meter)



WHY THE PACIFIC LOCKS OF THE PANAMA CANAL WERE CONSTRUCTED AS A TWO SEPARATE STRUCTURES RATHER THAN A SINGLE COMPLEX SIMILAR TO THE ATLANTIC LOCKS

BY ABELARDO VICENTE BAL RENAU

The location, number, size and height of the navigation locks in the Panama Canal was fixed after considering many possible solutions, in an immense effort which included studies, investigations and even construction failures. Many variables needed to be considered including excavation volume, lake volume, the local geology, construction and operation costs, navigation safety and water management. Based on historical documentation, an explanation is presented on why it was decided to build the Pedro Miguel and Miraflores locks as two separate structures in the Panama Canal.

Figure 1: The Panama anal Watershed

Figure 2: Profile of the Panama Canal

Water Supply for the Locks

The functioning of the Panama Canal requires a careful administration of its water resources. Vessels transit between the Atlantic and the Pacific oceans, navigating through two artificial lakes: Gatun and Miraflores. The system works by gravity. The water supply is provided by the rainfall which falls in a watershed of 3338 km² of area and the storage provided by lakes Gatun and Alhajuela, as is shown in Figure 1. The lakes are regulated by gated dams, to guarantee the water supply to the nearby cities and to maintain the proper levels in the navigation channel. A secondary benefit of the lakes is the generation of 60 MW of hydro-electric power.

Asymmetry in the Panama Canal

Figure 2 shows that there are navigation locks at both ends of the Canal. The locks are duplicated, that is, there are two ship lanes in each structure. The total distance between the Pacific and the Atlantic entrances is 80 km. On the Atlantic side, vessels are lifted 26 meters in three steps in the Gatun Locks to Gatun Lake. After navigating 52 km, vessels reach the Pedro Miguel Locks on the Pacific side, where they descend 9.5 m in a single step. They next navigate 1.7 km through Miraflores Lake and descend 16.5 m to sea level in two steps at Miraflores Locks. Given this asymmetry between the two ends of the Canal, the question arises: Why didn't the Panama Canal builders merge the three steps in the Pacific side in a single structure, just as they did in the Atlantic side?

Early studies

At the time of Spanish colonialisation, the idea of an interoceanic canal was presented to kings and discussed at the highest levels. Explorations were performed, showing special interest in the Chagres and Darien routes. But the project was later considered to be dangerous to the Spanish dominion of the region, since it could attract the covetousness of other nations. Panama became independent from Spain in 1821 and voluntarily joined Colombia.

First decisions on locks and lakes

Canal projects were then prepared by English, French and American engineers. In this investigation, fifteen projects with locks in the Chagres River route were reviewed. Tables 1 and 2 show the location and the number of steps in the locks for only five of those projects, the ones which were officially adopted by the entities in charge of the construction of the Panama Canal at those dates. The tendency over time was to have larger locks. A balance was always needed between the water supply and the water used in the locks.

The French project – Two steps in Pedro Miguel and one in Miraflores

The construction of the Panama Canal started when a French company, the Universal Company of the Inter-Oceanic Panama Canal, started the excavation of a sea-level canal in 1881. Due to severe difficulties with this scheme, the company in 1887 had to change its plan to a canal with locks (Project No. 1 in the tables). After the company went bankrupt in 1889, the New Company of the Panama Canal, also French, was founded in 1894. It did great progress in the canal design, but little in its construction. Double locks (two lanes) were introduced, with the main motivation to save water by using cross filling between parallel chambers. An interesting project considered by the French but not listed in the tables is the one by Wyse (1891), with three steps lumped into a single complex in the Atlantic side at Bohio and three steps lumped at Pedro Miguel in the Pacific side, with the Summit Lake at elevation 30 m. The new French company later developed in 1898 Project No. 2 shown in the tables, which was presented for sale to the United States Government. In the Pacific side, it had two steps in Pedro Miguel and one in Miraflores.

The American project – One step in Pedro Miguel and two in La Boca

The French project was slightly modified by the Isthmian Canal Commission (ICC), an agency of the U.S. Government and Project No. 3 was presented in 1901 (Ref. 2). Panama became independent from Colombia in 1903. The United States took possession of the Panama Canal on May 8th, 1904. The first chief engineer of the project was John Wallace. He was substituted by John Stevens, who arrived in Panama on July 26th, 1905. In order to finally solve the debate between whether the canal should be built at sea-level or with locks, President Theodore Roosevelt convened an international Board of Consulting Engineers to study the project. It was constituted by 13 renowned engineers, who departed for Panama on September 28th, 1905. A report was submitted on January 10th, 1906. The majority, eight of them, favored a sea-level canal, with a double tidal lock at Ancon and a dam at Gamboa for the control of the Chagres River. They were three Americans, two French, an English, a German and a Dutch. The minority, five Americans, supported the canal with locks. This is Project No. 4 shown in Tables 1 and 2, with one step in Pedro Miguel and two steps in La Boca at Sosa Hill (Sosa Locks). Sosa Lake was limited by the three dams shown in green and purple in Figure 3. The green dams were later changed to the locations shown in brown. The three dams to be built on the Pacific side were the following: Diablo-Corozal, Sosa-Corozal and La Boca, with a spillway at Sosa Hill.

The report of the International Board was accompanied by several letters of transmittal to the U.S. Congress (Ref. 3). One of them was from John Stevens, dated January 26th, 1906. He supported the lock canal project, commenting that on the Pacific side, based on military and sanitary reasons, he favored locating the locks at Miraflores and Pedro Miguel, instead of having part of them at La Boca. In another letter, The Secretary of War, William Taft, stated that the canal proposed by the minority of the Board could be built in half the time and a little more than half the cost of the canal proposed by the majority, and would also be safer to operate. A sea level canal could not be built in less than twenty years. The great objection to the locks at Sosa Hill was the possibility of their destruction by fire from an enemy's ships. Even though the lake would be useful as a means of relieving any possible congestion in case the traffic became very great, it was wiser to move the locks to Miraflores if Sosa Hill could not afford a site for such protection. Finally, President Roosevelt, in his letter dated February 19th, 1906, also supported the lock canal alternative and recommended the possible change of the site of the dam on the Pacific side. In his opinion, the American engineers favored the lock canal, whereas the foreign engineers were against it, partly because the great traffic canal reference of the Old World was the Suez Canal, a sea-level canal, whereas the great traffic canal of the New World was the Sault Ste. Marie Canal, a lock canal, which is located in Michigan, U.S.A.

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Three steps in Miraflores proposed

After submission of the lock-canal project and prior to its adoption by Congress, John Stevens evaluated plans for placing the three locks in flight at a place about a mile south of Miraflores. He wanted to remove the military objections raised by the Secretary of War and the operational inconvenience of the arrangement with the specified separation of the locks in the Pacific side. It was thought at the time that a suitable foundation had been located, but before these plans were submitted, additional borings and foundation explorations, necessarily made with great haste, indicated that the

Table 1: Projects officially adopted for the Panama Canal.

Project	Date	Number of Lakes	Summit Lake elevation (ft)	(m)	Steps in Atlantic side	Steps in Pacific side
1	1887	9	161	49.1	5	5
2	1898	4	102.5	31.25	4	3
3	1901	2	90	27.4	2	3
4	1906	2	85	25.9	3	3
5	1907	2	85	25.9	3	3

Table 2: Location of the locks. The number of steps is in parenthesis.

Project	Date	Atlantic Side	Pacific Side
1	1887	Bohio (1), San Pablo (1), Matachin (1), Corosita (1), Cascadas (1)	Escobar (1), Nitro (1), Paraiso (1), Pedro Miguel (1), Miraflores (1)
2	1898	Bohio (2), Obispo (2)	Pedro Miguel (2), Miraflores (1)
3	1901	Bohio (2)	Pedro Miguel (2), Miraflores (1)
4	1906	Gatun (3)	Pedro Miguel (1), La Boca (2)
5	1907	Gatun (3)	Pedro Miguel (1), Miraflores (2)

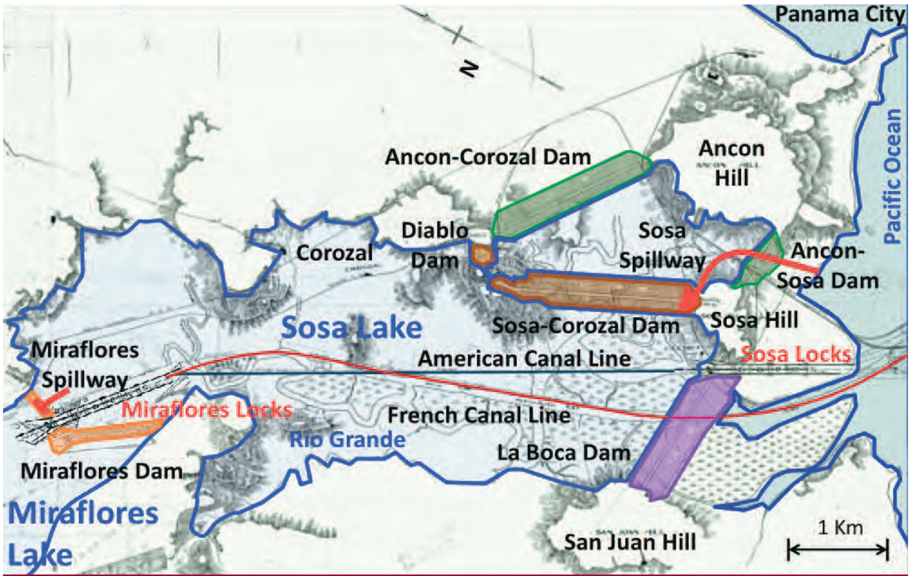

Figure 3: Location of the locks and dams in the Pacific side. The Sosa Locks were relocated to Miraflores in 1907. Based on Drawing No. 1527 of the Isthmian Canal Commission (ICC), November 1906, and on Plate 53 of the Annual Report of the ICC for the Fiscal Year 1909

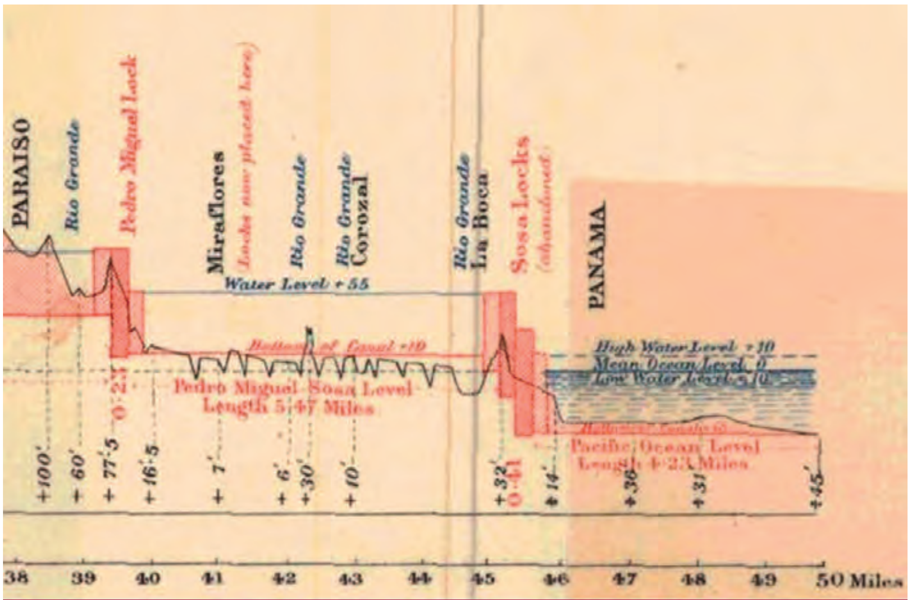

Figure 4: Longitudinal section of the Pacific side of the project adopted in 1906. The arrow shows the relocation of Sosa Locks to Miraflores in 1907. Based on a drawing by T. Fisher Unwin (London) titled "The Panama Canal from the reports of the Isthmian Canal Commission"

foundation was unsuitable for the needed structures. There was insufficient time to permanently settle the question of lock location. Also, advocates of the sea-level canal, were poised ready to take advantage of a major change in the approved program as evidence of weakness in the lock-canal solution. After considerable discussion and by a narrow margin, Congress approved the lock-canal project, with a flight of two steps at Sosa Locks and one at Pedro Miguel Locks on June 29th, 1906. In December of that same year there was a flood in the Chagres River which remained the largest of record until December 2010. That event could have reinforced the notion, among the engineers, that the lock-canal project was the best choice.

On August 3rd, 1906, Stevens approved a plan developed by William Gerig, with all the Pacific Locks in three lifts south of Miraflores. But, on August 23th, 1906, he voided this plan marking it, "not to be destroyed but kept in this office", since he was under great pressure to start construction of the approved project (Ref. 1, 4, 7 and 8).

President Roosevelt visited Panama on November 14th-17th, 1906. He inspected the work in the Canal and approved a more centralized organization of the ICC, with John Stevens as Chairman. But Stevens resigned in February 1907. He was succeeded as chief engineer by Colonel George Goethals, who arrived to Panama on March 12th, 1907.

Sosa Locks are abandoned

The advance in the construction of the Canal can be followed from "The Canal Record", the weekly newsletter of the ICC (Ref. 6). The excavation of the Sosa Locks started in July 1907. But as was explained by Goethals in The Canal Record edition of December 25th, 1907, "a poor material was found during the construction of the Sosa-Corozal dam. It was for the greater part an unctuous blue clay without grit, possessing but little supporting power, instead of stiff clay as indicated on existing profiles … Investigations of the foundations of the Sosa-San Juan dam show that the material is the same; the difficulties to be encountered will be greater, because of the river". The Sosa Locks were therefore relocated to Miraflores as is shown in Figure 4. Figure 5 shows the advance in the construction of the Sosa-Corozal Dam in December 1907.

Modified Project: One step in Pedro Miguel and two in Miraflores

According to Goethals, "an examination of the Canal route from Pedro Miguel to the Pacific was undertaken, to ascertain if more suitable places for the locks and dams could be found". A report with the investigations and studies was sent to Goethals on December 3rd, with a cost comparison of the following four projects (Ref. 6):

(1) One lock at Pedro Miguel and two at La Boca – USD 58.4 million
(2) Two locks at Pedro Miguel and one at Miraflores – USD 58.5 million
(3) One lock at Pedro Miguel and two at Miraflores – USD 50.9 million
(4) One lock at Pedro Miguel, one at Miraflores and one at La Boca – USD 66.7 million

The third project was chosen because it was the most economical. As a result, the three dams in the Pacific end were substituted by a new dam and spillway at Miraflores, which is shown in orange in Figure 3. Sosa Lake was reduced by about 80% of its area, to include only its portion located north of Miraflores Locks, and which today is known as Miraflores Lake. The alignment of the sea-level portion was changed to the old French Canal Line. This is Project No. 5 listed in tables 1 and 2. It is the project which was finally built.

Goethals reported these changes to the President on December 9th, 1907. President Roosevelt approved the changes on December 20th, 1907. On January 15th, 1907, Goethals defended in Washington the latest changes to the project in Congress.

Three steps in Miraflores reconsidered

It should be noted that the project with the the flight of three steps in Miraflores was not included among the four options considered by Goethals, even though the investigations which had been performed in 1906 under Stevens were submitted by Sibert to Goethals on December 3rd, 1907. Why not? A detailed explanation is given by Sibert in his book (Ref. 4, pages 139 and 140): "In addition to foundation troubles in the construction of the necessary dams, what triggered the search for a suitable foundation for the locks was the exposed position of the locks at Sosa Hill, La Boca, to ship-fire from an enemy's fleet. The search started at the old French lock location at Miraflores and continued south. The borings soon established the fact that suitable foundations existed at Miraflores for at least two locks. Work was proceeding, building the dams connecting Sosa Hill with the highlands on either side and starting the excavation for the Sosa Hill Locks, in case a change were to be made it was necessary that the decision should be arrived at quickly so as to stop expense on a project that might be discarded. When the question was brought before the ICC for recommendation, it was thought and stated by those conducting the explorations that there was not a suitable foundation for three locks at the site". DuVal mentions in his book (Ref. 7, page 292): "Goethals considered combining all the locks at Miraflores but found it would require a large concrete fill for a foundation, which would have been prohibitive".

However, as Sibert explains (Ref. 4, pages 140 and 141): "It was thought by some of the engineers that there would be a great advantage in having the three locks in one flight at Miraflores, making the two ends of the Canal symmetrical. Investigations were therefore continued and soon established the fact that the three locks could advantageously be built at Miraflores on a rock foundation, thus making it practicable to carry out a little further up the valley essentially the same plan that had been studied in 1906 and abandoned because suitable foundations had not been located. Comparative estimates were made and showed that the three locks on the Pacific side could be built in flight in a single structure for about USD 4,000,000 less than if separated."

Figure 5: East toe of the Sosa-Corozal Dam, 7 December 1907. Ancon Hill is shown in the background

Why the idea was not adopted

But if the project with the three locks in Miraflores was proven to be better, why was it not adopted? In page 7 of Notebook 17 of the Nichols collection of the Panama Canal, which is available on the Internet, appears the following statement made by Cornish, who was Design Engineer of the ICC, on January 2nd, 1908: "The conclusions of the Board are summoned up as follows: That the borings obtained so far, are not sufficient to enable a correct estimate of the cost of either project."

A comparison of the relative costs of constructing and maintaining the two projects was presented by Sibert to Goethals on January 31st, 1908 (pages 63, 64 and 68 of Appendix B of the ICC Annual Report of 1908). The drawings of the design with the three steps in Miraflores, mentioned in that Appendix B, were not found in this investigation.

DuVal describes with supporting documentation what happened next: "The project was referred to Colonel Hodges, who opposed it, for he considered the division of lifts as adopted, to be safer. Goethals sided with Hodges' views, because he considered him the best navigation locks engineer in the United States. Congress became interested. (Ref. 7, pages 296 and 297). The proposal was examined by a board of seven engineers, (which on February 16th, 1909) reported confidentially to the President that the better plan would be to build the three steps at Miraflores (Ref. 4, page 146). But Goethals thought the combination would seriously delay the completion of the Canal. He wanted to hasten completion; but, as the plant for the two locks had been ordered, a change would have caused a long delay. After carefully considering all the factors, Goethals explained on June 18th, 1909, that the project with the three steps in Miraflores could not be adopted, although the report was made to the President" (Ref. 7, page 297).

The Canal Record reported that by October 14th, 1908, the excavation of the north approach to Pedro Miguel Locks was practically finished. By January 6th, 1909, the excavation at Pedro Miguel Locks was about two-thirds done. On March 24th, 1909, at Pedro Miguel, preparation was being made for the laying of concrete in the locks, and the building of a dam was in progress. By June 1909, the excavation in the west chamber of Pedro Miguel Locks was completed to the floor level (Ref. 6).

Goethals was probably right in judging that it was too late to make such a big change in the project then, without having a serious impact in the cost and the schedule. But as Sibert points out (Ref. 4, page 146), another consideration was the impact on the public opinion: "An extended and bitter public discussion was then being carried on in the papers of the United States concerning the type of the canal. Changes in the adopted project could be utilized, it was thought, by the advocates of the sea-level plan in their arguments. Changes in plans were classed as admissions of weakness in the lock-type canal".

Conclusion

In this investigation, the following possible causes for the separation of the locks were analyzed: (1) The idea had never been formally proposed before. (2) Inefficiencies in the functioning of the ICC, possibly caused by changes in its organizational structure. (3) Defense considerations. (4) High cost or technical problems in the foundations of the locks. (5) Savings in construction costs. (6) Savings in operation costs. (7) Safety in the locks operations. (8) Advantages to navigation. (9) Water savings and faster transit times. (10) Cost savings due to smaller lock gate heights. (11) The political climate in the U.S.A. during the construction. (12) Impact of a change in plans in the construction schedule and a delay in the date of the opening of the Panama Canal.

The book by Sibert (Ref. 4) presents most of these issues in detail. The conclusion of this investigation was that only the last two possible causes could explain the decision taken to separate the locks in the Pacific end of the Canal. The communication and the technical competence of the members of the ICC was good. The problem faced by the ICC was that the foundation explorations at Miraflores where not complete when a decision was needed on where to locate the locks in the Pacific side. After the plan was approved by President Roosevelt, the ICC considered best not to make a change immediately afterwards, considering the negative impact that this could have had on the public perception of how the project was progressing. When all the information on the foundations was available, it was too late to make a change without a serious impact in cost and schedule.

As DuVal comments in page 297 of his book: "Perhaps there was no other course; but nowhere do we find that the reasons for making the change were submitted with sufficient force and clarity to convince authorities of its importance." It is difficult to know if the three steps would have been built together in Miraflores, had a more forcible argument for the change been made in December of 1907 or before. Prudence could have inclined the ICC for the adopted project anyway.

The investigation also concluded that it seems that there are neither technical nor economic reasons which could justify separating again the locks in the currently ongoing Panama Canal Expansion Project, which includes building a third lane of larger locks. The new locks are now being built in single complexes in both the Atlantic and the Pacific ends of the Panama Canal.

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CHAPERONING: COLLABORATION BETWEEN THE PANAMA CANAL AUTHORITY (ACP) AND CH2M HILL IN THE PANAMA CANAL EXPANSION PROGRAM

BY KAREN SMITS

Parts of this article have been published earlier in Smits (2013) Cross Culture Work: Practices of Collaboration in the Panama Canal Expansion Program

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ACP and CH2M Hill: an Introduction

One of the key components in the Panama Canal Expansion Program is the design and construction of the Atlantic and Pacific Locks. In order to manage this so-called Third Set of Locks project, the ACP Board of Directors, fed by expert support from around the world, decided to hire a program manager. Different from the common practice in project management, this external party would not be allowed to run the project autonomously. Instead, it was ACP's intention to have their employees managing the project while learning from experts on their side. With the publication of 'The Invitation to Bid for the Program Management Services' (further abbreviated as Invitation to Bid) the ACP announced the tender process. This document portrayed the scope of the program management services, the requirements for the program manager and the terms and conditions under which both parties should operate. In details, it described the skills and knowledge the project manager needed to convey and at which key positions in the project organization their advice would be required. The ACP (2007) put down the following objective for the program manager:

> Training both by working with the ACP personnel in performing Program Management Services and also by means of seminars, handbooks and any other material which would provide the ACP's personnel with the best training possible to acquire the skills necessary for assuming more responsibilities in the supervision of the Works.

Hence, the owner of the project *and* its contractor would have to work intensively together to conduct the project.
The well-known US Consultant CH2M Hill won the tender process and was appointed as the program manager for the Third Set of Locks project. CH2M Hill has a global presence of over 23,000 employees with expertise in consulting, design, design-build, operations and program management (CH2M Hill 2011). In August 2007, a group of CH2M Hill employees enthusiastically came on board the project. "We committed to deploy our core team together in three days," remembered CH2M Hill's Program Director indicating the urgency of their presence in the project (Interview May, 2010).

Chaperoning

In traditional project management operations it is common practice to hire a program manager to accomplish a project and give the entity responsibility, accountability and decision-making powers to execute the endeavor. The ACP, however, implemented a manner of collaboration whereby its employees were closely involved in the project execution's daily practices. This form of collaboration between the project manager and its client is what I call chaperoning. Box 1 shows definitions for chaperone.

> **Chaperone** is a person (as a matron) who for propriety accompanies one or more young unmarried women in public or in mixed company (Merriam Webster Dictionary).
> The word chaperone originates from the Latin word cappa ('cape') that referred to a hood used to protectively cover a person's head (Oxford English Dictionary).

Figure 1: Definitions of chaperone.

The chaperone, as an older, more knowledgeable body, guides a younger person, the novice, in how to operate in the unknown world. It explains what practices and behavior is expected, shares its embodied experiences and teaches the ins and outs of the new environment. CH2M Hill was hired to chaperone the ACP, and guide the organization in managing the Third Set of Locks project.

This unique practice of program management aims at giving 'training on the job' to the ACP employees, so that they, in the future, could perform the tasks on their own. On an everyday basis in this project, chaperoning entails a form of collaboration in which two employees are hired for one key position: an ACP employee and a consultant from CH2M Hill worked together in a 'one-on-one' structure. The consultant acted as the chaperone and the ACP employee was, as a novice, expected to absorb and understand how complex projects are to be managed.

Experiences with Chaperoning

Although roles were clearly defined in the Invitation to Bid, in practice it appeared that both CH2M Hill consultants and ACP employees experienced difficulties on the work floor. From the start, CH2M Hill employees felt uncomfortable in the chaperoning role. Even though their names appeared above the ACP employee's name in the organization chart, indicating superiority, the consultants did not have the right to control or power to determine the project's development. They felt frustration when their advice was not followed and experienced a lack of support on how to conduct the teaching aspect of their job; the role of a 'trainer on the job' was new to most CH2M Hill consultants.
The ACP employees, on the other hand, had

mixed feelings about the collaboration with the CH2M Hill consultants. Several ACP employees did not recognize the value of an advisory capacity or were afraid that 'the Americans' would soon take over leadership of the project. Conversely, there was a group of ACP employees in favor of assistance in the management of this mega project. These ACP employees found CH2M Hill's presence beneficial, mostly because a majority of the regulations, processes and values within the ACP originate from the American era, and thus, were well known among the CH2M Hill consultants. Steve, an ACP Team Leader Assistant, emphasized his positive feelings about CH2M Hill's role in the project:

> "A design/build contract is something new for ACP. We need to recognize that we don't have the know-how to deal with it. We have been doing excavation works, but this is the first locks project that we are going to face in this generation. […] The project content is not difficult; it's the magnitude, the size of the project that overwhelms us. We regret that we don't have that experience, we don't have that now and therefore we need somebody to guide us." (Interview, March 2010)

Steve underscored that the ACP employees lacked sufficient knowledge and experience in the management of mega projects. The CH2M Hill consultants, on the other side, often complained about their role in the project and the attitude of the ACP employees. William, a CH2M Hill Project Site Manager, expressed that, although there was a contractually agreed mentor role for the consultants, he felt that the ACP employees were not motivated to learn from the CH2M Hill consultants. In an interview he told me:

> "If you have a mentor-protégé relationship, it's important that the protégé wants to be mentored by the mentor. And that goes beyond respect. I might respect you for who you are, but that does not mean that I will take in what you say. I may not absorb your advice. Or adjust my own practices. So, that being said, we have not the easiest relationship to work with. [It is] a very hard relationship to work with." (September 2009)

Sensing an adverse attitude towards the consultants, William emphasized that the collaborative relationship between the ACP employees and CH2M Hill consultants was rather complicated.
Chaperoning appeared to be a problematic endeavor. One such case in point was related to the nature of the two organizations: the ACP is a public organization and CH2M Hill is a private company. Coming from differing work environments and practices, project participants often subscribed conflicts amongst them to the differing root characteristics of their organizations. CH2M Hill's Kristin stated that collaboration between the ACP and CH2M Hill was complicated due to the differing work environments of the organization.

> "ACP is very - what's the word I'm looking for? – very regimented. Their procedures are very detailed and very strict, something that I'm not used to. […] Here it is all very slow. So that is like a big change for me (sighs). I try to be patient; I'm not a patient person by nature. I just keep reminding myself that this is a different company. It's a different culture. Everything is different in ACP and they are a governmental agency so I have to keep reminding myself that there are regulations in place that I may not be aware of." (Interview, March 2010)

She professed bureaucracy as a root characteristic of the ACP and felt this was a burden in her everyday work. The ACP employees acknowledged their organization had many lengthy procedures; however, they did not recognize those as a threshold in their daily operations. Pointing at their root characteristics, the organizational values of the ACP and CH2M Hill contrasted. For example, the billability from CH2M Hill and the public values carried out by the ACP were set square. For CH2M Hill values as time and money were important. Moneymaking was one of the organizations main motives. On the other hand, the ACP was focused on its services to the local community and the public at large; the public good was its driving factor. 'For the people of Panama' was an often-heard reasoning for working at the Panama Canal. Serving the public good, transparency was one of the main organizational values for the ACP, resulting in open, but lengthy procedures.

Despite the initial differing interpretations of collaboration, work practices and organizational characteristics between the two parties, both the ACP and CH2M Hill decided to stay with the contract and work towards an integrated team as defined in the Invitation to Bid. The ACP Managing Director verified:

> "We have chosen the hardest way to execute a project. It would have been a lot easier when it would have only been ACP, or only CH[2], that would be a lot easier. But, one of our goals was that the ACP people get experience from somebody that has done this before. There would be no added value to have hired them to do 100 percent of the work. And it was too high of a risk to do it only with ACP people who have never done something like this. So, [pause] oh well, we're working it out. We'll make it work […]." (Interview, June 2010)

[2] Project participants often abbreviated CH2M Hill with 'CH'.

Figure 2: Common versus chaperone practices in program management

	Common Practices	Chaperone practices
Contract	Client hires Program Manager	Client hires Program Manager
Responsibility	Program Manager is responsible for project outcome	Client is responsible for project outcome
Accountability	Program Manager is accountable	Program Manager is not accountable
Risk	Risk is divided between client and Program Manager	Program Manager does not carry risks regarding the program
Leadership	Program Manager leads the execution of the program	Client leads the execution of the program
Training	No training aspect	Training is highly important, the Program Manager trains the client
Supervision	The client supervises the Program Manager's results	The Program Manager supervises the work of the client
Collaboration	Moderate collaboration between Client and Program Manager	Intense collaboration between Client and Program Manager

Collaboration between the ACP and CH2M Hill was challenging, but both parties had expressed the spirit to do anything in their power to succeed. And so, to date, they continue working together on the management of the construction of the Third Set of Locks project.

Conclusion

In the Panama Canal Expansion Program CH2M Hill was hired to assist the ACP in their role as program manager of this mega project. Its tasks were to guard budget- and time schedules and to advice the ACP employees in their daily operations. However, the different expectations of how collaboration should come about created tension between the two parties. At the start of the project CH2M Hill consultants expected to carry responsibility, to be held accountable and to carry risks in the execution of their work. To them, these were among the common practices in managing mega projects. In contrary, the ACP prescribed chaperoning practices in the Invitation to Bid. Box 2 provides an overview of the common practices and the chaperoning practices in project management.

It shows that the ACP merely assigned supervising and training tasks to the program manager and kept all authority and liability to itself. In the daily practices, however, this study shows that CH2M Hill employees felt uncomfortable in the role they were expected to carry out, as chaperoning practices were new to them. These differing expectations of how collaboration between the program manager and its client resulted in power struggles and conflicts among the project participants.

In this specific case, chaperoning practices portrayed both benefits and drawbacks for the project outcomes. Benefits are the transfer of knowledge to the local situation of the client, as well as the high level of trust that is built in such a close relationship between client and program manager. Another benefit is the increase of understanding for 'the other' in the collaborative relationship. Drawbacks of chaperoning are found in personal misfit and conflict. Another drawback is the questionable durability of the transferred knowledge and the translations of new expertise to future practices.

Chaperoning practices can serve other projects if daily work practices receive more attention. Since practices of collaboration are not fixed at the start of a project, the discussion about how collaboration should come about in the project organization needs to be stirred up. Serious attention to the practices of collaboration enhances the collaborative relationship among partners, which can prevent cost overruns and delays in project outcomes.

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THE PANAMA CANAL FLOOD CONTROL PROGRAM

BY JOHNNY A. CUEVAS M

The Flood Control Program of Panama Canal Authority (PCA), is a set of activities performed during the highest rainfall season, to identify, mitigate and respond to various flood conditions that could pose danger to communities and properties located on the riversides of reservoirs Gatun and Alhajuela, and that may affect the structures and could disrupt the operations of the Canal. The spills are the most critical activities, which are executed for safety reasons for the Canal. In the Panama Canal Watershed the Flood Control season usually begins in August and lasts until mid-January,and involves different activities to achieve the goal of reaching maximum operating levels of the reservoirs to ensure water availability throughout the year, for the three main uses, municipal use (human consumption), the lockages and hydropower generation.

Because the program is fully dynamic in 2005, the communities previously identified, that can be affected by the spills, were included in The Flood Control Program by means of a risk community management plan.

The Plan ensures that the spilling operations take into consideration the safety of the communities located downstream and above the reservoirs and to prevent damage to the structures of the Canal itself. The drills of the plan are key in keeping the staff from different areas of the Canal and the communities at risk autonomously prepared, in case of extreme flood events .

The Panama Canal could not have faced and successfully mitigated the effects of the "La Purisima" storm in December of 2010, without a properly structured and previously rehearsed plan.

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Introduction

The Control Plans for an Emergency Flood, have been developed to reduce the adverse impacts of major flood events on economic, social and physical aspects of an area. However, it was not until recent decades that they have gained acceptance among governmental agencies and the general public as a means to mitigate flood damage [Probst, 1992].

The importance of testing the procedures of the Panama Canal Authority and the release capabilities of the structures to defeat a flood was duly recognized when the flood control exercises (FCE) were started in 1972. Like a human being, the watershed always is changing, for these reasons it must be checked and updated annually mainly due to anthropomorphic changes in the basin that may impact the runoff coefficient of the basin due to changing land use.

A common problem in the world is population incursion onto the flood plain, which always begins immediately a dam has been build. This problem emerges in response to population growth and pressure on natural resources results in the incursion of inhabitants in the floodplains of rivers and reservoirs.

There are potential risks associated with spills from Madden Dam and spillway such as: erosion of banks and riversides, damages to bridges, flooding communities downstream, strong currents in Gamboa and danger for tourists, and residents due to strong currents.

The reservoirs management poses a challenge for hydrologists working at the ACP, especially during the last three months of the year, as they have to maintain the lake elevations as high as

possible to cope with the dry season and for instance there is no room left for flood control [Vargas, 1996]. Examples of the occurrence of storms over the last months of the year that cause flooding are: October 1923, November 1931, November 1932, November 1966, December 1985 and December 2000, November 2004 and as recently as December 2010.

Results of the flood control exercises, there were critiques that we were doing with the residents of the communities located downstream from Madden Spillway. In the case of a severe flood condition that causes extraordinary spills, how the PCA could support these communities? Identified the risk to these communities, the PCA took the initiative to establish a risk community management plan to integrate it into the flood control program.

The hypotheses proposed was that in order for the risk management program to be effective and successful the community inhabitants should have the ability to follow the procedures of the plan on their own.

Flood Control Program

The Flood Control Program of the Panama Canal Authority (ACP) is the set of activities that the Section of Water Resources (EAAR) performs during the period of greatest precipitation to identify, mitigate and respond to different flood conditions that could pose a danger to communities and properties adjacent to the reservoirs, in addition to affecting the operations of the Canal.

The Flood Control season usually occurs from September to January and the activities carried out include: the revision and update of the Flood Control Manual (FCM), the revision and update of the Flood Control Operations Manual of the Branch (EAAR), preparation of memoranda designating personnel authorized to request the opening and / or closing of the spillways gates; update and preparation of notifications lists to all stakeholders involved; hiring of five Hydrology Assistants who work shift hours, shift schedule preparation and designation of teams that continuously monitor meteorological conditions in the Panama Canal Basin, attend regular meetings of change of shift to discuss hydrometeorological conditions and when the reservoirs are reaching peak operation levels, perform inspections of the communities located in the flood plains at risk of flooding due to spills carried out and preparing and issuing notices or warning bulletins of flood risks due to spills operations and extreme weather conditions to the communications

Figure 1: Doppler weather radar

media targeted at communities and the general public.

Flood Control Exercise

One of the main activities is the execution of Flood Control Exercises and drills which usually take place annually on the third week of October, and consists in a coordinated simulation, which serves as training for PCA staff in the actions and procedures of spilling operations and helps them identify possible problems and solutions. Participants also test and evaluate the flood emergency plans and the lines of communication between different units involved during a flood. The exercise also includes several steps including: meetings, lectures and training of personnel, yearly exercise and the exercises critiques.

Because the branch is responsible for preparing, updating and publishing the Panama Canal Authority's Flood Control Manual and the Operations Flood Control Manual of the Water Resources Branch, both manuals are evaluated during yearly exercises in order to be used during real flood situations.

The exercise involves the participation of stakeholders from different units of the Panama Canal Authority that may be affected and/or needed in the case of severe flooding. Additionally, other government entities responsible when such events happen are invited to participate.

As an example, from a study of the flood control exercise in 2004, the following questions surfaced: In the event of a flood in the communities of Santa Rosa and Guayabalito: Do you have a census?, Do you have an evacuation plan?, Where do you evacuate?; Who should I contact?, Do you have food, blankets, etc.)?.

In 2009, the flood control exercise used for the first time the Incident Command System (ICS). The ICS is an organizational structure used by many governments and industry to manage all types of emergencies in a standardized manner. When the application of this system is properly planned and practiced with the institutions involved, it becomes the most effective structure for managing emergency response of medium and large scale.

Support Systems

The telemetry system is the backbone of the flood control program because it allows continuous monitoring of the hydrometeorological conditions of the Panama Canal Watershed through the information generated in the field in real time. Other support systems include satellite images / NOAA Port, the rawinsonde observation, doppler weather radar (Figure 1), forecast models and the Meteorological and Hydrological System and the Decision Support System (DSS). Also Floodplain Maps of communities at risk of flooding have been defined and updated.

All items listed above allow the hydrology team, to make accurate forecasts used to optimize the reservoirs management and to monitor extreme hydrometeorological conditions.

Spilling Structures

The Flood Control Program depends on the system of dams and spillways in order to regulate the elevations of Gatun and Alhajuela Lakes. The purpose of hydraulic structures is to regulate the storage of water throughout the year to ensure enough water during the dry season. The Panama Canal Authority has three main hydraulic facilities for flood control: Gatun spillway, Madden dam and spillway and the locks culverts. The Gatun spillway consists of fourteen vertical sliding gates, the Madden spillway has four drum gates and six sluice gates and in case of flood emergencies 3 culverts at Gatun locks and 3 culverts at the Pedro Miguel locks can be used to discharge up to 764 m^3 per second and 594 m^3 per second of water in each location.

The Program of Maintenance of dams and spillways is responsible for ensuring that the entire system is available at the beginning of the flood control season.

From Flood Control to an Integrated Flood Control Program

Although, there was a well-structured flood control program that guaranteed the safer and continuous operation of the Panama Canal, there still were challenges that needed to be overcome. In 2004 it was acknowledge that the Flood Control Program needed to integrate and connect the communities that were vulnerable to flooding through a communitarian risk management plan.

Establishment of the Risk Community Management Plan

The communities of Guayabalito and Santa Rosa were identified as the most vulnerable

Figure 2: Introductory talk to Risk community management plan. May 2006

because they are located in the floodplain of the Chagres River. A joint effort conformed by a multidisciplinary and institutional team which included members of the Relations with the Community Unit of the Environmental Division of PCA and the Sistema Nacional Protección Civil (SINAPROC) begun to performed the following major activities:

- Community diagnosis in October 2005 and characterizing communities Guayabalito and Santa Rosa in January 2006
- Cross Sections and Surveying of the communities: Landmark in field of the elevation 30.48 m, contour of housing and infrastructure location and mapping, in March 2006
- Training workshops to organize and establish the Community Risk Committee, May-July 2006 (Figure 3)
- Scholar risk workshop in the School of Santa Rosa, October 2006
- Information for residents on the height 30.48 m, 2006
- Preparation of management plan of flood risk, in October 2006 and validated in the community of the Risk Management Plan, 2006
- Evacuation Drill and assessment in October 2006
- Community Environmental Management Workshop, 2007
- Signing of a cooperation agreement between the Ministry of Government and Justice, through SINAPROC and PCA, December 2007
- Workshop for update the flood risk plan
- Meeting school workshop flood risk in the school of Santa Rosa, 2007
- Call and updating database Guayabalito communities and Santa Rosa, 2008
- Exercise evacuation of people with non-participating observers National Police, SINAPROC, ACP, 2008
- Involvement of community coordinators in the introductory talk to the Practice of Flood Control 2009 and 2010, the Ascanio Arosemena Training Center
- Install warning signs in flood risk areas and evacuation routes in September 2009.

Results

The activities previously carried out in the communities of Santa Rosa and Guayabalito, had successful results, because the inhabitants were involved and has been training in a risk management culture and by themselves , follows the procedures established in the plan; achieved an updated population census of both communities; prepared, updated and shared a list of notifications of persons and agencies to call in case of flood emergencies; marked the contour of 30 m elevation reference and other landmarks; placed evacuation routes signs, specified accommodation location for both communities and finally promoted active participation of residents of the communities through the flood controls drills.

The Integral Flood Control Program was duly tested on December 7, 8 and 9 of 2010, when the storm called "La Purisima", struck the basin of the Panama Canal. The high volume of water dumped by the storm required the spilling of 4340 m^3/s from Madden spillway.

The "La Purisima 2010" Storm

The "La Purisima 2010" storm was a product of the interaction between a low pressure system and a pre-frontal trough associated with the cold front. From December 7 to 9, 2010, a stationary storm – the largest in the history of the Canal - hit the Isthmus, affecting operational areas, mainly in the northeast region of the watershed, resulting in heavy amounts of rainfall which caused more than 500 landslides that eroded a significant amount of forest and mud.

The probability analysis of the average maximum rainfall recorded in 24 continuous hours for the period 1972-2010, indicated that the storm had a return period of:

- 108 years for the Gatun Basin (same as the PCW)
- 69 years for the Downstream Sub basin (sub basin located downstream of Madden Dam),
- 113 years for the Alhajuela Reservoir Sub basin (sub basin located upstream of Madden Dam)
- In the 39 years that were analyzed, the five biggest storms have taken place in the last 10 years

The maximum precipitation in the Alhajuela Reservoir after 24 hours of "La Purísima 2010" was five times greater than the average record for the 1906-2009 period and in the CHCP (joint precipitation in Alhajuela and Gatun) reservoirs it was 4.3 times greater than the average record over the same period.

The result of the analysis according to the frequency distribution probability Log-Pearson Type III (FDP LP III), indicated that the maximum rainfall in 24 hours for the Alhajuela reservoir established in 3693 m^3/s, between December 8^{th} and 9^{th} , 2010, has a return period of 167 years. Likewise, for the PCW the analysis indicated that the return period is 116 years for a maximum rainfall of 7600 m^3/s between December 8^{th} and 9^{th} . When compared with the estimated return periods for the average maximum rainfall in 24 hours, it was found that the rainfall had a longer return period in the Alhajuela reservoir sub basin (167 versus 113 years), perhaps due to the greatest level of soil saturation in the area most affected by the storm throughout the PCW, where the return periods were similar (116 versus 108 years).

Extraordinary precipitation volumes associated to "La Purísima 2010", surpassed the storage capacity of the Alhajuela and Gatun reservoirs, making immediate emergency operations necessary to spill excess water in order to ensure safety conditions and to comply with the Panama Canal Authority's mission of operating the Canal.

The Impact on the Operations of Madden Spills

The levels of the water profiles reached 30 m in height and over, so that homes located below this elevation, were under water.

Among the main consequences was the flooding of homes located on the floodplains of the Chagres River in the communities of Santa Rosa and Guayabalito, where only property suffered damages (furniture, appliances, furniture, etc.). The telemetry station of Santa

Rosa was also flooded, requiring the removal of electronic equipment to prevent damage; riverbed and the banks immediately downstream of Madden dam were eroded; the highway Alberto Motta was partially closed at the Chagres River bridge section, affecting transit between Panama and Colon; the spilling operations also affected the Hotel Gamboa Resort Marine the navigation channel in the area of Gamboa because all the vegetation and debris carried downstream; and the ship transits needed to be reschedule due to 17 hours delay. Table 1 shows the total number of people affected totaling 99 people.
For example, the spilling operation from Madden of 4340 m^3/s per second was enough to fill 3 Olympic pools in two seconds.

Table 1:Total of Families Affected

Families	Families affected	Adults	Children	Total persons
TOTAL	27	56	43	99
Guayabalito	5	10	9	19
Santa Rosa	22	46	34	80

Source: Inventario ACP. Equipo Social de Investigación y Relaciones con la comunidad y Equipo de Educación Ambiental.

Conclusions

Spillway operations were conducted following the procedures established under the Flood Control Manual, which requires timely notification of evacuation, enforcement of this action, and considers all the provisions written in the Risk Management Plan of the communities of Santa Rosa and Guayabalito that were practiced in previous flood control exercises, thus prevent human losses of residents from these communities.
It may be pointed out that the proper response of the communities to the call of evacuation, due to spilling operation, allow them to leave their homes following evacuation routes and reach in time previously identified and established safe havens during the event.
A recently introduce Incident Command System proved to be a useful tool to meet the emergency.
The Canal could not have successfully faced and mitigated the effects of the storm "La Purisima" without the proper design and structuring of a flood control plan, which is kept updated periodically; the training in flood control management of the staff of Water Resources Branch (meteorologists and hydrologists), other ACP staff involved in the operations and other institutions such as SINAPROC through annual drills; and the empowerment of the community through the risk management plan.

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THE NEW PANAMA CANAL: **IMPACTS**

BY REECE F. SHAW AND JAMES DENTON-BROWN

The new Panama Canal locks are being built to accommodate ships with a total fresh water (TFW) draft of 50 feet, a beam of 160 feet and a length of 1,200 feet. This compares with the current canal limits of about 41 feet draft, 110 feet beam and 1000 feet length. Once opened in 2015, the new canal is expected to have a significant impact on US ports with the primary impact expected to be substantially increased traffic at the US East and Gulf Coast ports and a decrease on the US West Coast ports. *NB: In the following article all dimensions are given in US units wherein 1 foot is equivalent to 0.30 m in SI units*

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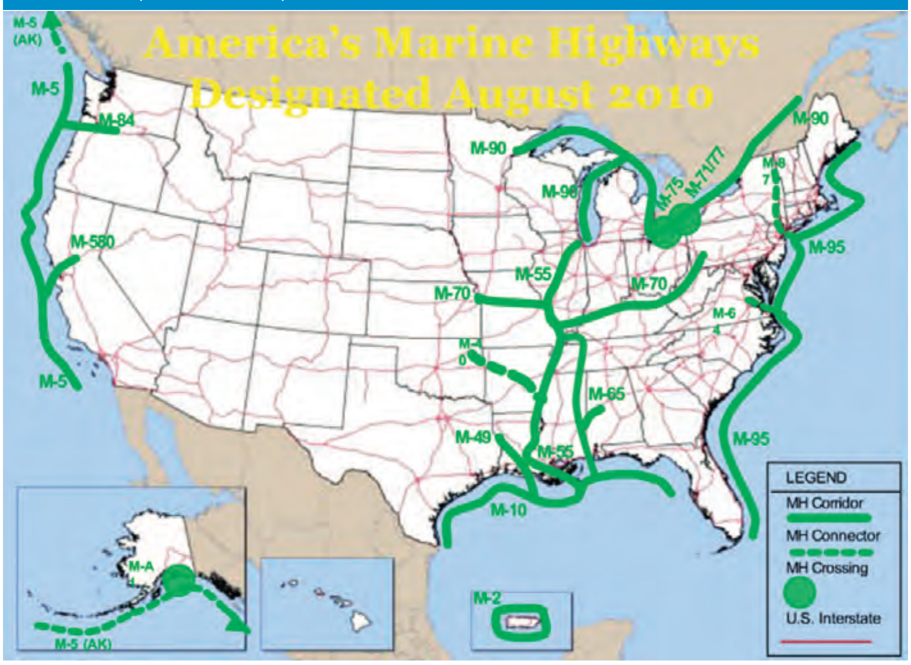
Jim Denton-Brown **is the Manager of Planning for Bechtel Civil Infrastructure in San Francisco, California. Jim has an MBA in Management and Economics from the University of Maryland, College Park, Maryland and a BS in Environmental Design and Planning from California Polytechnic University, San Luis Obispo, California.**

This is due to the fact that the new canal will eliminate the cost advantage that West Coast ports currently have in handling large container ships arriving from Asia whose loads are then moved to the east coast via rail. The much larger ships able to transit through the new canal will shift the cost and time advantage from the West Coast ports to the East Coast ports that are able to handle the larger ships. According to the US Army Corps of Engineers (USACE) Institute of Water Resources there are likely to be two additional impacts:

- To take full advantage of the larger vessels coming through the canal, a large deep water transshipment port located either in the Caribbean or along the US coast is likely to be developed. The largest vessels would unload containers at the transshipment port for reloading on smaller feeder vessels for delivery to other US ports with less draft and capacity.
- On the export side, the ability to employ large deep draft bulk vessels is expected to significantly lower the delivery cost of US agricultural exports to Asia and other foreign markets. This would have a significant impact on the total quantity of US agricultural exports and commodities moving down the Mississippi River for export.

Most existing US East Coast ports are unable to handle the New Panamax ships and have a maximum draft of about 40 feet or less. However, there are exceptions including the ports at Hampton Roads and Norfolk (50 feet) in Virginia, Baltimore (50 feet) and New York (50 feet). In addition to these, Charleston, with a 45 foot channel depth and nearly 5 feet of tide, can accommodate New Panamax vessels at high

Figure 1: Map of Marine Highway Corridors
Source: U.S. Department of Transportation, Maritime Administration



AND OPPORTUNITIES IN THE USA

The Mississippi inland waterway system connects over a dozen Midwestern states with the Gulf of Mexico

Figure 2: Inland waterway map centered on the Mississippi River
Source: PNO Master Plan

tide during a two hour window and Savannah can do so marginally with 48 feet of dredged depth.

For Gulf ports, Gulfport in Mississippi, New Orleans, Mobile and Houston have maximum berth depths of 45 feet or less. None of these ports are currently funded to be deepened to 50 feet.

Ports that are hoping to accommodate New Panamax ships must also consider air draft (the distance from the surface of the water to the highest point on a vessel). The New Panamax ships have an air draft of 201 feet. The eastern seaboard ports of New York and New Jersey are constrained by the Bayonne Bridge which has an air draft 151 feet. The Port of New Orleans is constrained by both channel depth and air draft. The federal channel in the Mississippi River is maintained to a depth of 45 feet up to Baton Rouge and the Crescent City Connection bridge in New Orleans - the farthest downstream bridge on the Mississippi River – has an air draft of 170 feet at low water and 155 feet at high water.

The ports hoping to take advantage of the shift in cargo flows must also consider the movement of goods from the ports to inland destinations. Therefore, landside capacity and good highway connectivity is essential in being able to handle and move the large quantities of containers and bulk products quickly and efficiently to and from onward locations. This is often one of the most serious problems facing existing ports, many of which have highly congested and inefficient inland connections created by dense existing city development surrounding the port.

An Alternative Approach: America's Marine Highways

The federal government has been promoting the rehabilitation and improvement of America's Marine Highways as an alternative to highway congestion on roads and railroads (see Figure 1). These navigable waterways have been designated by the Secretary of Transportation and have demonstrated the ability to provide additional capacity to relieve congested landside routes serving freight and passenger movement.

The program is designed to focus on the integration of Marine Highways into the nation's surface transportation system, providing seamless transition across all modes by leveraging marine services to complement landside surface transportation routes.

Marine Highway Centered on the Mississippi River

The Mississippi inland waterway system shown in Figure 2 is an inland waterway system that connects over a dozen Midwestern states with the Gulf of Mexico. The M-55 Corridor includes the Mississippi and Illinois Rivers from New Orleans via St. Louis to Chicago and on through Louisiana, Mississippi, Arkansas, Tennessee, Missouri, and Illinois. It includes connecting commercial navigation channels, ports, and harbors. It connects to the M-90 corridor at Chicago, the M-40 Connector in AR, crosses the M-70 Corridor at St. Louis, and meets the M-10 Corridor at New Orleans.

At 2,348 miles in length, the Mississippi River is the second longest river in the United States and 92 percent of the nation’s agricultural exports are produced in its basin. Sixty percent of all U.S. grain exports move on the Mississippi River and the largest port in the United States (by tonnage) is the Port of South Louisiana which is located on the Mississippi at LaPlace, LA. The Port of New Orleans handled 476,413 containers (TEUs) in 2011, most of which also move inland on truck and rail.

It is extensive but limited to depths of less than 15 feet for the most part. As noted above, the port at New Orleans has a maximum berth depth of less than 45 feet, limiting the containership capacity to less than 5,000 TEUs. Under such circumstances, ports along the Mississippi are primarily handling barges loaded with agricultural commodities, which implies a highly seasonal traffic (end of the summer and fall). The Lower Mississippi ports are dominated by dry bulk trades like coal, grains and ores, along with a wide variety of other commodities. When viewed from the perspective of the ability of inland waterways to support enhanced export opportunities that a global fleet of larger ocean going vessels represent, those inland waterways that serve a hinterland with desirable export commodities are of particular interest. Logistics/transportation entities at New Orleans have developed new methods of loading commodities to containers that previously only moved in bulk.

Deep-water Gulf Coast Transshipment Hub Options

There are basically three Gulf transhipment hub options which would support the U.S bound vessels transiting the New Panama Canal:

- **Existing Gulf Coast Ports.** We have already seen that the Gulf Coast ports of Gulfport, New Orleans, Mobile and Houston have maximum berth depths of 45 feet or less and are unlikely to be deepened to 50 feet. Hence, this option does not address the potential of the large vessel Transshipment Hub.
- **Competing hubs within the Caribbean.** Several transshipment hubs exist and have been proposed both in the Caribbean and along the Gulf Coast. Of the major competing hubs within the Caribbean, only Freeport in the Bahamas (dredged depth of 51 feet), the in process container ports in Colon Panama (dredged depth of 52 feet) and Moín Costa Rica (approach channel dredged to 62 feet) can accommodate the New Panamax vessels. While these ports can function as oceanic transhipment hubs, they cannot serve the needs of U.S. river cabotage which is dominated by non-oceangoing river barges.
- **Deep Water Gulf Coast Ports.** A floating offshore trans-shipment port complex located about 20 miles off the U.S. coasts has been proposed by Lawrence Livermore National Laboratory (LLNL), in its security research project called Portunus (see Figure 3). If such a complex were to be situated along the approach to the Mississippi River, it could serve as both an oceanic transhipment hub as well as a hub serving large river barges. This terminal would have no draft restrictions but would be orders of magnitude more expensive than a conventional landside port.

An Alternative Concept

A fourth option has been recently proposed at the mouth of the Mississippi River, called the Louisiana International Gulf Transfer Terminal (LIGTT). This port is envisioned to be a trans-shipment port providing a logistics “hub-and-spoke” system for containerized cargo located on 250 acres at River Mile 0 of the Mississippi River. The site would provide for water depths of 75 feet on the Gulf of Mexico side. With no road or rail access, the terminal will rely on state of the art efficient intermodal logistics to decrease costs and speed up throughput.

Although the project is still in the concept stage, it is drawing interest and support and would be able to capture the opportunity provided by the new Canal at a location best able to handle the large deep water ships while simultaneously delivering products to and from the Mississippi River Marine Highway system.

Figure 3: The off-shore port concept would allow cargo to be inspected far away from cities to increase homeland security
Source: LLNL Community New July 2, 2010, VOl. 3, NO. 26, Illustration by Mark McDaniel/LLNL

Conclusion

Clearly a New Panamax container and commodity transhipment logistics hub port focused on serving the U.S. Gulf Coast and providing major port transhipment gateway services to North America is needed. Intermodal bound containers and bulk cargo shipped through such a hub would be received from various sized international transshipment vessels afloat after passage via the new expanded Panama Canal, from ports across the Atlantic Ocean, or from ports throughout the Western Hemisphere. The LIGTT appears to be the most viable option identified to date.

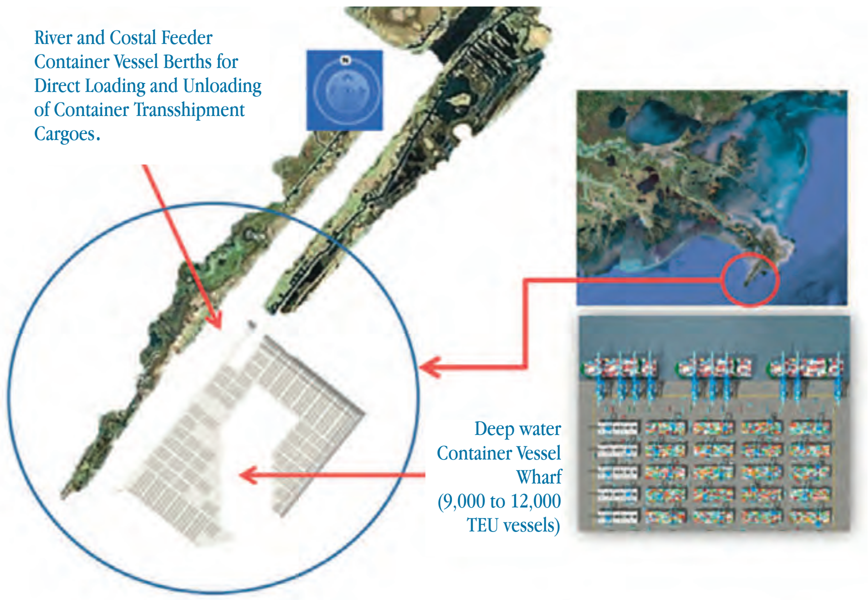


Figure 4: The LIGTT deep water transshipment hub concept - located at the mouth of the Mississippi inland waterway system
Source: Louisiana International Gulf Transfer Terminal Authority Website, http://www.ligtt.com/index.html

PEOPLE & PLACES

2014 New Institute Members

IAHR welcomes its newest Institute Members

- Bureau of Reclamation, United States of America
- Panamerican University, Mexico
- Norwegian University of Science and Tecnology, Norway
- Jucar Basin Management Office, Spain
- Universidad de Costa Rica, Costa Rica
- Prince Sultan Bin Abdulaziz International Prize for Water, Saudi Arabia

New Deputy Editor of JAWER

Teodoro Estrela, Head of the Hydrological Planning Office of the Jucar River Basin Management, is the new Deputy Editor of JAWER, taking over from Ramiro Aurin who will become Deputy Editor of RIBAGUA, the new IAHR-WCCE Spanish and Portuguese-language journal.

Alvaro Sordo-Ward has moved to the Politechnic University of Madrid, Spain

He is now Lecturer in Hydrology and Hydraulics.

A sad moment

Prof. Lin Bingnan

Prof. Lin Bingnan, senior academician of Chinese Academy of Science, honorary member of IAHR and honorary president of China Institute of Water Resources and Hydropower Research (IWHR), passed away on January 3, 2014 at the age of 94 years old.

For the full obituary and to leave a condolence message, please go to the IAHR website under the obituaries section.

Alfred Lang has retired from Andritz

Alfred Lang is former Chair of the Hydraulic Machinery Committee and member for many years, and used to be the Managing Director at Anstalt Für Strömungsmaschinen Gesellschaft MbH (Andritz Group) in Austria. He has been replaced by Arno Gehrer.

Thanos Papanicolaou has moved to the University of Tennessee

Papanicolaou is now Professor and Goodrich Chair of Excellence of the Department of Civil & Environmental Engineering, The University of Tennessee, USA. He was formerly at the Department of Civil and Environmental Engineering–Hydroscience & Engineering- at the University of Iowa, IIHR- since 2003 where he worked on a wide range of hydraulic and environmental issues.

New Vice Chair of the IAHR Experimental Methods and Instrumentation Committee

Rui Aleixo, Visiting Research Associate at the National Center for Computational Hydroscience and Engineering (NCCHE) - University of Mississippi, USA.

New journal in Spanish and Portuguese - joint venture of IAHR and WCCE

AQUAE FUNDACIÓN

IAHR jointly with WCCE – World Council of Civil Engineers- is preparing a new publication called RIBAGUA – The Spanish and Portuguese Journal of Water in Iberoamerica.

The Journal will be published by Elsevier and it is sponsored by Aquae Foundation. The Aquae Foundation was created with the aim to become a national and international focal point of reference in the sphere of water from a holistic standpoint.

The Journal will publish academic and technical content on water issues in Latin America and Iberian Peninsula.

RIBAGUA will be free for IAHR members in this region.

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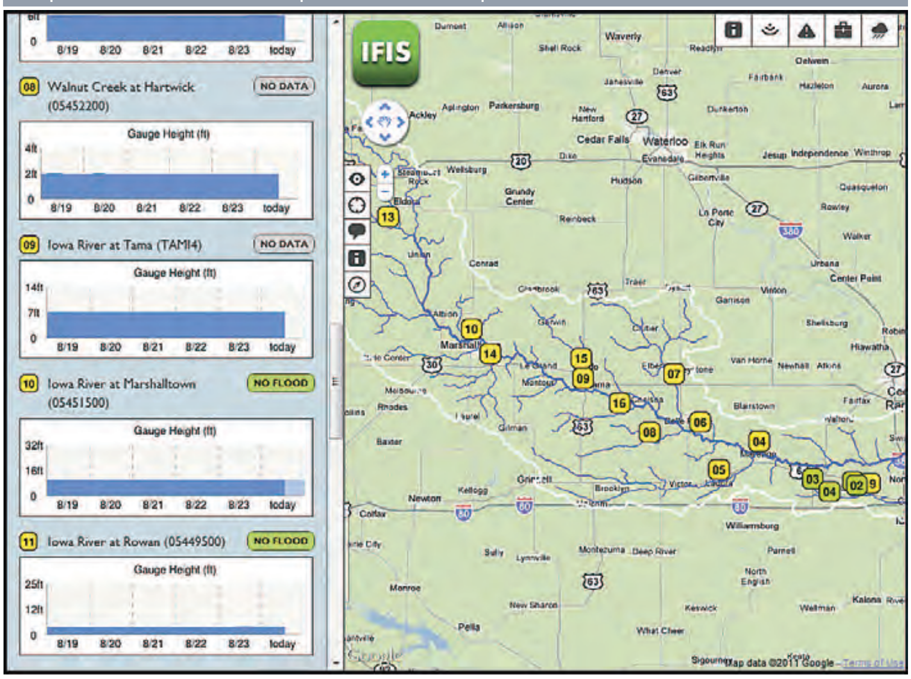
THE IOWA FLOOD INFORMATION SYSTEM MAKES IOWANS SAFER, BETTER INFORMED

For nearly a century, IIHR–Hydroscience & Engineering has been a global leader in the field of fluids-related research – but students and researchers at IIHR are focused firmly on the future. One of the most exciting and groundbreaking areas of research at the institute is the work of the Iowa Flood Center, which is helping Iowans learn to "live with floods." The need for enhanced flood information has been made clear time and again in Iowa, where extreme rain events and flooding have threatened lives and resulted in billions of dollars in damages.

Based at the University of Iowa, IIHR's mission is to be a leader in fluids-related fundamental and applied research; to provide interdisciplinary education for future leaders in science and engineering; and to advance knowledge in support of sustainable natural and engineered systems. IIHR researchers have been actively engaged in many IAHR activities, including the highest leadership levels (John F. Kennedy and Forrest Holly as past presidents, Marian Muste as vice-president). IIHR has been an IAHR Institute Member since 1959, playing an active role in integrating results of experimental, numerical, and analytical investigations in hydraulic design and widely sharing the research findings with the hydroscience community.
The Iowa floods of 2008 provided the impetus for the Iowa state legislature to create the Iowa Flood Center (IFC), based at IIHR. IFC researchers began collecting time-sensitive data on many aspects of the flood — from high-resolution data to document flood water elevations to contaminated sediments deposited by flood waters. The flood helped catalyze the formation of new teams of researchers from across the university to work together with water-related agencies on flood-related initiatives. The IFC is now actively engaged in flood projects in many Iowa communities and employs several graduate and undergraduate students participating in flood-related research. IFC researchers designed a cost-effective sensor network to better monitor stream flow in the state; they also developed a library of flood-inundation maps (Gilles, et. al., 2012) for several Iowa communities.

IFIS provides visualization of multiple sensors in a river path



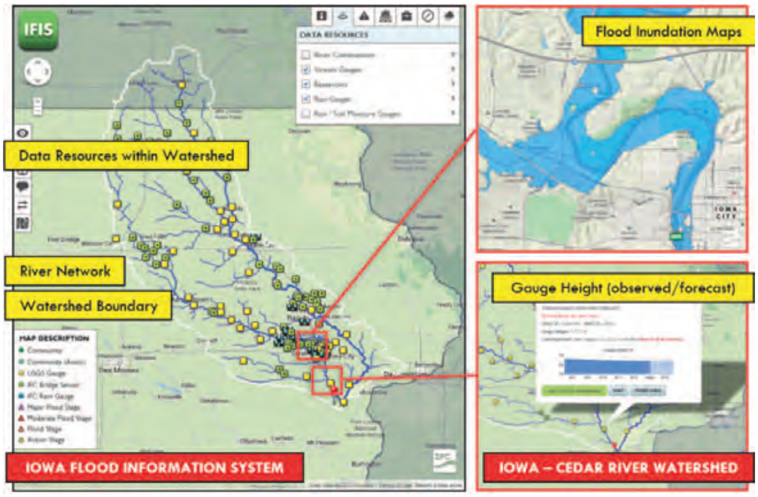
When floodwaters rose yet again in the spring of 2013, Iowans had innovative new tools that hadn't even been dreamed of five years ago – thanks to IFC's focused research designed to help all Iowans be better prepared for future flooding. The IFC's Iowa Flood Information System (IFIS, Demir and Krajewski, 2013), is a one-stop hydroinformatics web-platform to access community-based flood conditions, forecasts, visualizations, inundation maps and flood-related data, information, and applications for more than 1000 communities in Iowa. IFIS provides community-centric watershed and river characteristics, rainfall conditions (Seo and Krajewski, 2010), flood information, and streamflow data and visualization tools for Iowa communities. Basin boundaries and river network depiction provide users with the hydrologic context of the water flow and allow them to better understand the potential flooding conditions in their community. Some of the main features of IFIS include:

- Real-time stream levels at 398 locations in Iowa
- Current flood warnings and stream forecasts for more than 1,000 communities in Iowa
- Real-time rainfall maps displaying current conditions and past rainfall accumulations
- Flood inundation maps for select communities
- IFIS provides real-time and forecasted river stages and interactive inundation maps

Witold F. Krajewski **is the director of the Iowa Flood Center. His research interests concern multiple aspects of rainfall measuring, modeling, forecasting, and estimation, using radar and satellite remote sensing. His work at the Iowa Flood Center focuses on understanding the genesis of floods through field experimentation and modeling, as well as the quantification of uncertainty in hydrologic prediction at a range of temporal and spatial scales.**

Ibrahim Demir **is a research engineer at IIHR–Hydroscience & Engineering and the Iowa Flood Center. His research interests are environmental information systems, scientific visualization of geo-spatial data, user interface design, and information communication. He is the architect and developer of the Iowa Flood Information System.**

This article has been assembled by Jacqueline Hartling Stolze, Lead Communications Specialist IIHR—Hydroscience & Engineering, University of Iowa.



IFIS provides real-time and forecasted river stages and interactive inundation maps

Researchers and students at the IFC designed and built a network of affordable electronic stream water-level sensors that are attached to the downstream side of bridges; the sensors provide part of the real-time data that is such an important part of IFIS. The sensors provide Iowans with up-to-the-minute reports on water levels in Iowa's rivers and streams. In a situation where information and preparedness can save lives, the sensors provide a vital service for Iowans. In 2010, the Iowa Department of Natural Resources purchased 50 of these sensors, which the IFC deployed in vulnerable locations across the state. The success of this project led to the continuation of this partnership — and 50 more sensors. Working with the DNR, the Iowa DOT, and others, the network now totals about 160 sensors. "This is truly a statewide collaboration," says IFC Director Witold Krajewski. "Sensor site locations are based on community requests. And the people in these communities know best which streams and rivers in their areas need improved monitoring."

Flood inundation maps of 12 flood-prone Iowa communities are also useful during flood events. Users can visualize the potential extent of flooding at a range of river levels. Homeowners, business owners, and others can see how predicted flood levels might affect their property. This information helps individuals and communities plan and make sound mitigation decisions. Nathan Young, associate director of the Iowa Flood Center, says the IFC has been developing flood inundation maps since the center was launched about four years ago. "This is an opportunity for us to apply research that is useful and meaningful for Iowans," he says. "Our maps demonstrate not just a 100-year flood or a 500-year flood, but also the extent of the flooded landscape with every six-inch rise in the projected flood level. We believe this extra measure of preparedness can save property, resources, and lives." Maps for additional communities are added to IFIS each year. For additional information on the development of the community-based flood inundation maps, visit: http://www.iowafloodcenter.org/ projects/flood-inundation-maps/.

IFIS also includes a rainfall-runoff forecast model to provide a five-day flood risk estimate for more than 1,000 communities in Iowa. Multiple view modes provide different user types (general public, researchers, decision-makers, etc.) with varying levels of tools and details. River view mode allows users to visualize data from multiple IFC bridge sensors and USGS stream gauges to follow flooding conditions along a river. Krajewski says, "Initially, the IFC focused on providing critical information to Iowans related to flood risk and current flood-related conditions. This will always be an important part of our mission. In my vision for the future, we will continue to expand the IFC's scope, as well as study ways to decrease flooding by considering entire watersheds – not just localized levees and flood gates." IFC and IFIS will both continue to help communities make better-informed decisions on the occurrence of floods, and will alert communities in advance to help minimize flood damage.

To access IFIS, go to http://ifis.iowaflood-center.org. From this page, users may launch IFIS, or watch a brief video tutorial on how to use the system. IIHR and the Iowa Flood Center are always looking for outstanding graduate students – visit http://www.iihr.uiowa.edu/ education to learn more about opportunities for students.

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