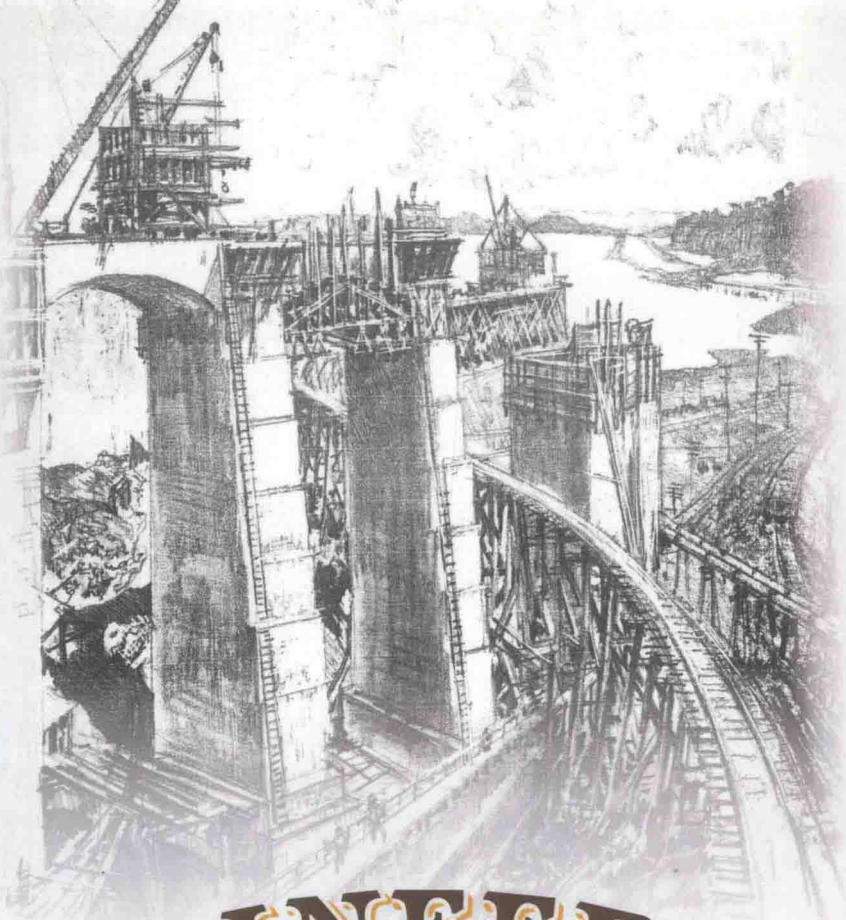

ENGINEERING THE PANAMA CANAL

★★★

A Centennial Retrospective

EDITED BY
Bernard G. Dennis, Jr.

ASCE

ENGINEERING THE PANAMA CANAL

A CENTENNIAL RETROSPECTIVE

PROCEEDINGS OF SESSIONS HONORING THE 100TH ANNIVERSARY OF THE PANAMA CANAL AT THE ASCE GLOBAL ENGINEERING CONFERENCE 2014

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Introduction

The history of a canal at the Isthmus of Panama extends for centuries, one of many outcomes of Christopher Columbus' search for an ocean route from Europe to the Indies. The early chapters of this tale involve some well known characters associated with the discovery of the Americas (Ojeda, Pizarro, Balboa, Cortéz); Spanish colonies and the Spanish Main; and, French, Dutch, and British pirates of the Caribbean (Drake, Morgan, Cook). In 1513, Spanish settlers discovered two oceans separated by a narrow strip of land - the Isthmus of Panama. The idea of a canal to link the two oceans was first proposed by Álvaro de Saavedra Cerón who accompanied Balboa and Cortéz in explorations of Central America and did extensive surveys of the Isthmus between 1517 and 1529.

Multiple locations for a canal were surveyed and mapped, but no actions were taken to initiate construction. Interest was renewed toward the end of the 18th and early 19th centuries, when British interests encouraged surveys of four routes for a canal. Spain decreed that a canal be constructed through the Isthmus and subsequently, the US entered the picture when approached by the Federal Republic of the United Provinces of Central America after it seceded from Spain in 1823. Several efforts to launch contracts for a canal were unsuccessful. However, an offshoot of these efforts resulted in the construction of a railroad linking the oceans which, when completed in 1855, still fell short of the desired canal.

The subject of our attention for this centennial celebration is the next chapter of the saga, which begins in 1876, when Columbia granted the French a concession to build a canal across Panama. It's a multifaceted story of exploration, adventure, political intrigue, engineering and social challenges, financial wheeling and dealing—a story with sufficient twists and turns to hold one's interest and keep the pages turning.

We are fortunate to have a bounty of records and photographs documenting this period of the canal development. As a product of the US government, it was well documented in regular reports to the President and Congress, as well as the nation via continuing newspaper coverage to a population that devoured the epic stories. Books, such as Ira E. Bennett's 1915 *History of the Panama Canal*, David McCullough's 1977 *The Path Between the Seas,* and Julie Greene's 2000 *The Canal Builders*, among others, give wonderful accounts of this era. Other sources include the US Congressional Records; the Library of Congress; and records in the US National Archives, which include many thousands of photographs. Library collections from the University of Florida's George A. Smathers Libraries and the Panama Canal Museum (http://ufdc.ufl.edu/pcm), and the Linda Hall Library in Kansas City, MO provide wonderful access to information and documentation on the birth of the Panama Canal.

To celebrate the 100th anniversary of the opening of the Panama Canal, ASCE's annual conference was held in Panama in October 2014. Recognizing this opportunity, ASCE's History and Heritage Committee worked with ASCE's Conference Planners to include history sessions in the conference. To deliver the history sessions, speakers were asked to submit their papers for publication in conference proceedings. What resulted is this document in which we present superb papers discussing a number of topics, providing conference attendees and lay readers a glimpse of the story of the Panama Canal. These papers document the lives and experiences of the engineers and others who struggled to get the dream accepted, funded, launched, and built, in order to ensure its successful operation over the last 100 years.

The proceedings are organized in the same sequence as the presentations during the four history sessions at the ASCE Conference. The "Early Years" provides two papers focusing on British efforts to study the possibility of a canal across the Isthmus, followed by the French efforts at constructing a canal across Panama. It is interesting to note that, although the French efforts failed, it was not due to the engineering. The adage "timing is everything" can be applied here in the subsequent US efforts, which benefitted from the lessons learned from the French. Their experiences in fighting malaria and yellow fever in Cuba; advances in equipment resulting from the westward expansion and development of the railroad in the US; spoils and experiences gained from the Spanish-American War; and, good old Yankee ingenuity, allowed them to adapt means, methods, and machinery to unique conditions.

The second history session addressed "Building the Canal." The railroad was a key component in the canal construction, and the experience of the construction itself. US engineers with railroad construction, equipment, and operations experience were essential to the successful completion of the canal. The ability to operate track mounted equipment for both excavating and hauling dirt and rock excavated to form the canal channel made the construction possible. Laying out and moving tracks continued throughout the job, a story recounted in this segment. The construction of the locks and gates from movable, rail-mounted cranes is another key element of the construction process.

The third history session examines the "Men Responsible" for moving the canal through the decision process, and those who were responsible for designing and constructing the canal. The first paper provides insight into the many hurdles two individuals, Morrison and Bunau-Varilla, faced in moving the dream forward. It's a lesson on perseverance in championing an idea—one you believe in—despite the obstacles in your path. Following this is a paper on the men who actually worked on constructing the canal. It's a lesson in giga-project development, management, and execution. It shows that the right men in the right situation can achieve what seems impossible. They each had the knowledge and on-the-job training that prepared them for the challenges faced in Panama. A third paper presents an interesting view of the "Wonders of Work"—the art of engineering and construction as seen through the

lithographs of a famous American artist of the time, Joseph Pennell. Pennell travelled to Panama to document the fleeting moments of activity at construction sites. It is interesting to note that images of these works were also captured by many amateur photographers—sightseeing visitors to the site armed with another new technology, the Kodak camera.

A bonus paper is included that outlines the experiences of a young engineer from Japan who arrived in Panama fresh out of school to work on the largest construction project in the world. It chronicles his advancement from draftsman to chief engineer on the Panama Canal, experiences that shaped his future engineering career and achievements with waterworks in Japan. This paper was given during the conference in a separate session by the Japan Society of Civil Engineers, highlighting joint cooperation between JSCE and ASCE.

The fourth history session presented two papers that addressed activities "After Completion" of the Panama Canal in August 1914. The first looks at the Gatún Dam, which was the largest earthen dam ever attempted up to that time. It points out many of the challenges that were encountered well before modern geotechnical engineering theory and practices. It also examines the performance of the dam and efforts to analyze and upgrade it to meet current seismic threats. The final paper outlines a unique event that occurred following the completion of the canal—the 1915 World's Fair held in San Francisco, CA. While the exposition showcased San Francisco's reconstruction following the devastating 1906 earthquake, a major exhibit was a working model of the Panama Canal, specifically the Miraflores and Pedro Miguel Locks. That same year, many engineering symposia sponsored by US engineering societies published volumes of their transaction proceedings. One 1916 two-volume set of "Transactions of the International Engineering Congress, September 20-25, 1915 in San Francisco," included 25 papers by key engineers who worked on the canal, including Goethals, McDonald, Seibert, Williamson, Hodges, Mears, and others. Two of the original 1916 proceedings papers are reviewed. It is important to acknowledge the contribution of engineers from the Panama Canal Authority who contributed to these final two papers during a very challenging period in the canal's Third Set of Locks Expansion Program.

For those who attended the ASCE conference, this publication will be a reminder of the excitement and adventures we shared in Panama City in October 2014. For those who could not attend, this volume will introduce some of the excitement, challenges, and adventures that accompanied the building of the Panama Canal. Hopefully, these papers will inspire you to read and explore this era further. It's the history of an ASCE Historic Civil Engineering Landmark—the story of civil engineers on a world-changing project that achieved a century milestone: 1914 to 2014!

I wish to extend my sincere thanks and appreciation to the authors who contributed their time and talents to these proceedings and the ASCE Conference. It was my extreme pleasure and privilege to work with you, allowing me to be the first

to review these wonderful stories of the history of the canal and the engineers who made it possible. They are truly an inspiration, and you are to be commended for sharing their lives and achievements for future generations of civil engineers, just as their efforts have enriched our own. Again, thank you.

Readers, enjoy.

Bernard G. Dennis, Jr.
Chairman,
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Contents

UK Britain and the Trans-isthmian Dream

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ABSTRACT

From the late eighteenth century until the end of the nineteenth century Britain was unchallenged as the premier mercantile and maritime nation. With enormous financial resources and a growing territorial empire based around naval power it inevitably took an interest in the possibility of a transport link across Central America, as a financial investment and trade route.

At the start of the century Thomas Telford was called upon to advise upon the Darien Canal scheme. Although this came to nothing, leading British engineers and capitalists continued to look at rail and canal schemes. Finally at the end of the century the consortium of Cutbill, Son and De Lungo, and James Perry worked at Culebra on the disastrous French enterprise.

This paper summarises British engineering involvement, drawing on the ICE archives, and consider how many of the ideas were more than 'castles in the air'.

INTRODUCTION

The successful construction of the Panama Canal in the early twentieth century was a triumph of US engineering management, and medical knowhow. The existing Panama Canal was nearly half a century in the making and is generally acknowledged as one of the engineering wonders of the world. Engineers had to contend with both engineering difficulties, notably major landslides, and also disease, which decimated the workforce. That problem had to be addressed before the civil engineering challenges. However, in the pre-history of the scheme to create a transport link across Central America the British played a significant role over a long period of time.

In the sixteenth century the piratical activities of Sir Francis Drake involved the first crossing of the Isthmus by Englishmen. As British trade and the territorial empire grew, more legitimate interests in shortening sailing times and improving access to Asia and the Pacific Coasts of the Americas resulted in a series of schemes by British speculators and engineers to cross Central America. A number of surveys were made, and canal and rail schemes considered. In some cases there was serious outlay of capital, and transport links were completed.

In the second half of the nineteenth century, whilst British territorial imperialization was limited across Latin America, British capital and engineering were to be seen everywhere, generally in tandem. That France and the United States are generally associated with the Panama Canal has obscured the British interest.

PANAMA AND THE INSTITUTION OF CIVIL ENGINEERS

'Atlantic and Pacific Communications' was the subject of 4 papers and meetings at the ICE in the nineteenth century, reflecting the topics significance to the profession. No other potential project attracted such attention. The first was a summary of potential routes by Joseph Glynn (Glynn, 1847). This was notable for the presence of the future Napoleon III, who was an informed advocate of the Nicaragua Canal. The second, by J. A. Lloyd (Lloyd, 1849) was in a supplement to Glynn, giving further details of his surveys. The third (Kelley, 1856) was by the American, Frederick Kelley, and focussed on a sea level canal by the southerly Atlantic route, although summarising other alternatives. That paper was presented at a period of heightened interest, prompted by the Californian Gold Rush and Napoleon III's active sponsorship of a route. There was then a hiatus until the end of the century when J T Ford gave the fourth paper on summarising the De Lesseps scheme and its aftermath (Ford, 1900).

These discussions were complemented by donations and acquisitions by the ICE Library, encompassing government reports, engineering surveys, company prospectuses, and ranging in extent from single sheets of paper to weighty monographs. In addition were the numerous periodical articles. In terms of extent only the Suez Canal can compare. One reason for this, of course, was that so much was speculative.

What follows below is based on these ICE resources.

THOMAS TELFORD AND EARLY SURVEYS

Following the disintegration of Spanish America at the start of the nineteenth century, the newly independent states sought investment in a number of schemes including communications across Central America to link the Atlantic and Pacific. Perhaps the most interesting early scheme was that originating around 1818. On 27 January the British Consul in Panama was approached by the Colombian Government (then Government of New Grenada) with a view to Captain (later Lieutenant-Colonel) John Augustus Lloyd surveying a route across the Isthmus.

Apparently, ICE's President, Thomas Telford was first approached in 1825. In 1827, Lloyd and the Swedish engineer, Captain Falmark, finally began two seasons of surveys on behalf of Simon Bolivar's Government. Nothing happened. Bolivar died in December 1830 and Lloyd was posted to Mauritius. Telford, however, retained a large bundle of drawings, now lost, on the Isthmus of Darien scheme. It is a little known aspect of his career [ICE (1834)].

Lloyd's proposals were published by the Royal Society and Royal Geographical Society, and later by ICE. Of the Chagres river he noted: "The banks are precipitous, of trap and porphyritic formation, worked to the every edges ..." A hint of the arduous environment is given in his description of Portobello ... "Such is its dreadful insalubrity, that at no period of its history did merchants venture to reside in it ... No class of inhabitants can long exist in it." Telford was fortunate to be in Westminster giving his views, rather than on site with Lloyd.

LIEUTENANT COLONEL JOHN AUGUSTUS LLOYD (1800-1854) (Associate of the ICE)

Lloyd can be regarded as the first great British advocate of a Panama Canal (Lloyd, 1830; 1831; 1847). With rudimentary scientific education and some training in mining, engineering, and surveying he secured an introduction to Simon Bolivar, and became a Captain in his Engineering Corps. Despite his letter of authority of 29 November 1827 to survey the 'provincia del Darien del sur' he met with much harassment by local officials, which must have impacted the value of his surveys. He followed the Camino Real, or track across the summit ridge, and made no attempt to identify the lowest crossing point. He did however determine the levels between the Atlantic and Pacific, identifying both canal and rail routes. He drew two potential railroad routes on his map (Figure 1), believing a railway was both feasible and a necessary precursor to a canal. He believed the engineering of a canal to be practical, provided the finance could be found. Once built, he believed a canal would be easier to maintain with an abundant water supply. He also believed a good harbour could be built at Panama.

Lloyd saw the Isthmus as rich in resources, with an abundance of building materials – limestone and timber. He collected many geological and mineral samples which he presented to the British Museum, and Admiralty. On the Pacific side he believed the canal should start at Le Min, and then a canal be cut to Lima. From there the Rivers Chagres and Torindad would be made navigable to a point inland which could be the construction camp.

Lloyd recognised a labour force would be required. He suggested convict labour could be used – escape would be unlikely in a hostile environment – or black labour from the Caribbean or Africa. He also believed the interior would be attractive to European colonists (Lloyd, 1831).

Lloyd was not the only British engineer in Colombia in the 1820s. Both Robert Stephenson and Richard Trevithick were there, and Stephenson took a view that a canal could be built, and that construction materials were available (Lloyd, 1849, 79).

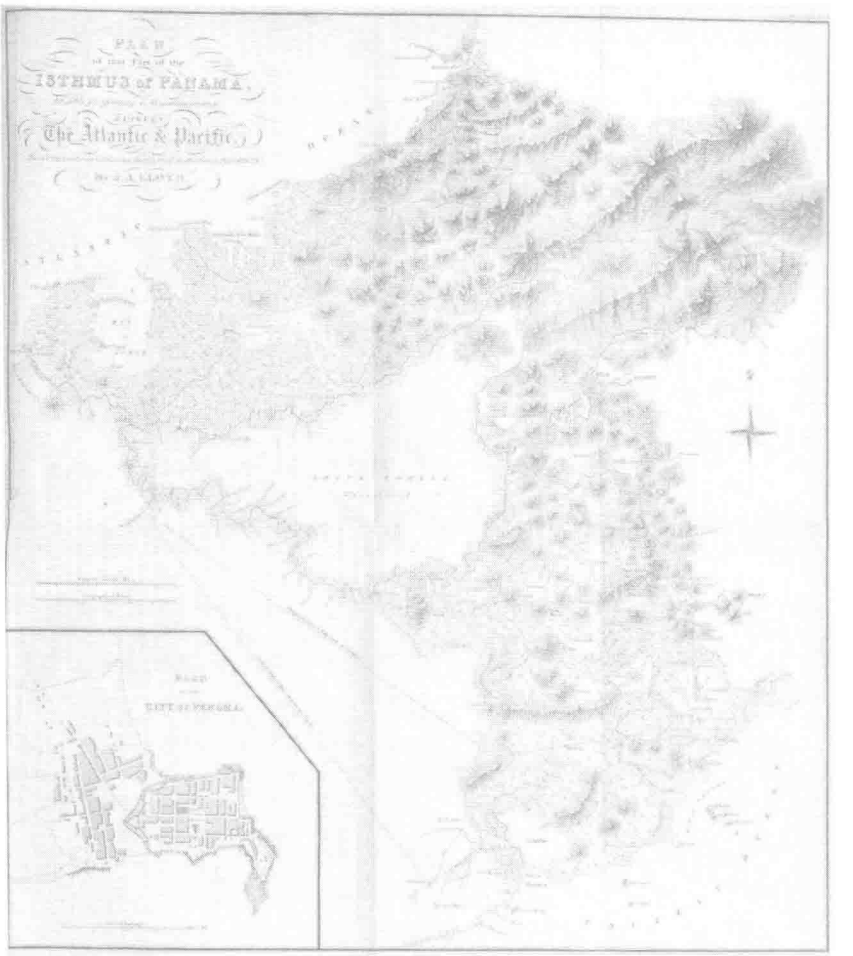

Figure 1. Lloyd's Survey of Panama
Lloyd's map, published by the Royal Society of London (Lloyd (1830)), was the first published map to show potential transport routes across the Isthmus

TEHUANTEPEC ISTHMUS

First surveyed by Craven in 1774, in 1824 Mexico set up the Tehuantepec Commission, and a survey was carried out in 1842-1843. J. J. Williams surveyed the route for a US company in 1851. Political instability and distance precluded progress for more than 30 years.

EVAN HOPKINS' SURVEYS

The Hopkins family were a well-established family of engineers active in South Wales and South West England in the early nineteenth century (Skempton, 2002).

Evan Hopkins (in Lloyd (Lloyd, 1849) 74) was employed in 1847-1848 by the Government of New Granada to survey the Isthmus from Darien to Veraguas. He investigated the geology and topography of the region, and concluded there were two feasible communication routes between the Atlantic and Pacific – in the Isthmus of San Blas, and between Chagres and Panama. His exploration of San Blas and the River Bayano was limited by the hostility of the indigenous population, although he concluded parts of the Bayano could be made navigable. He ruled out an old Spanish made track between Portobello and Panama as impossible to improve. His recommended route (Figure 2), essentially for a railroad, but also for water communication, followed the Chagres river to Gorgona, across the ridge, which he estimated at 260 ft above the Atlantic sea level, to the Rio Grande, following that river to Panama. His view of available building materials and resources was at odds with Lloyd and others.

Figure 2. Hopkins 1847-48 Survey
Evan Hopkins map indicates the difficult terrain he encountered, and was arguably the first by a British civil engineer.

PACIFIC STEAM NAVIGATION COMPANY

In the late 1830s British commercial interests promoted a steamship company with connectivity across the Pacific, and in their pamphlets spoke of railroads across the Isthmus. In 1838, the American William Wheelright (Wheelwright, 1838) issued a pamphlet on this proposal.

NICARAGUA CANAL

The appeal of Nicaragua compared to shorter crossings at Panama and elsewhere was the existence of lakes to reduce the need for construction. In 1781 the Spanish engineer, Manuel Galisteo surveyed the levels from the Gulf of Papagayos to Lake Nicaragua.

In 1826, John Baily was invited to survey a crossing through Nicaragua on behalf of an English company. Although nothing was done then in 1837-1838 he surveyed a route for the Government of Central America, following the Rio San Juan from the Atlantic to Lake Nicaragua and thence by a 15 2/3 mile canal to the Pacific at San Juan del Sur. This involved major navigation works on the San Juan, and an enormous volume of muck shifting (Baily, 1844). Harbour facilities were meagre. A further survey of the San Juan River by George Laurance was made in 1840.

An alternative route, first suggested by Gallisteo, was looked at by Dutch engineers in 1830, and the US in 1835. This avoided cutting through the ridge, and instead making use of Lake Managua, the Rio Tipitapa, and joining the Pacific at Realejea.

Further alternative surveys by US-based engineers in the early 1850s all concluded the necessary works were expensive. By mid-century ICE were able to publish Michel Chevalier's map (Figure 3) showing favoured routes (Glynn, 1847).

Under Napoleon III, French interest in the Isthmus increased. In 1859, James Samuel (1824-1874) and Alexander Woodlands Makinson (1822-1886) first went to Panama to verify French surveys on behalf of British business interests. Samuel, by background a railway engineer, in 1863, surveyed the potential route of a ship canal from Greytown, up the River San Juan, across the lakes of Nicaragua and Managua, to Tamarindon on the Pacific. He rejected the proposal as far more expensive than the French had estimated. He went on to become Chief Engineer for the Railway for Veracruz to Mexico City and Puebla (*The Times*, Picayune, 28 August 1863).

NICARAGUAN RAILROAD

A British naval captain, Bedford Pim, promoted the International Atlantic and Pacific Junction Railway through Nicaragua in the early 1860s. An Associate (i.e., non-civil engineer) of the ICE, he visited Nicaragua in 1860 and 1863. A Concession was signed between the Nicaraguan and British Government in 1860, and the civil

engineer, John Collinson, among others, surveyed the route (Collinson, 1866; Maury, 1866). Inevitably capital was unavailable.

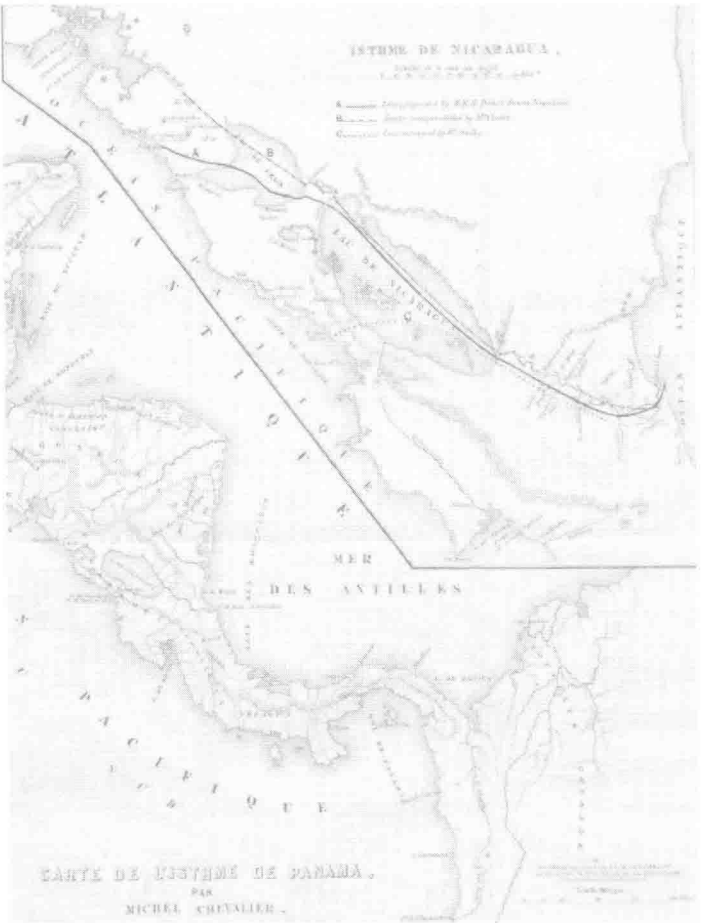

Figure 3. Isthme de Nicaragua
Michel Chevalier's map indicates alternative routes across Nicaragua (from Glynn, 1847)

(BRITISH) HONDURAS INTER-OCEAN RAILWAY

The American Ephraim George Squires(1821-1886) carried out surveys in 1853 and 1858, for a railway on behalf of an international consortium led by British capitalists.

ATRATO SCHEME (DARIEN): ATLANTIC-PACIFIC CANAL

A southerly route across the Isthmus attracted a great deal of interest in the City of London in the early 1850s. A series of pamphlets were issued by the Atlantic and Pacific Junction Company, promoting a route along the Atrato-Cupica Valleys. Charles Nixon MInstCE and his partner, Lecky, issued an engineer's report, weak on detail. Lionel Gisbourne criticised the route (Nixon and Lecky, 1853).

The route was commented on by the Manx-born American, William Kennish (1799-1862 in 1853. At the end of 1853, the US, France and UK agreed to support further surveys for this company. The route was surveyed by 6 British engineers: Armstrong, Bennett, Bond, Devenish and Forde, led by Lionel Gisbourne, but his critics felt Gisbourne took fright at the challenge of jungle surveys, and his negative views were heavily criticised by Dr Edward Cullen (Cullen, 1856; 1857). He persuaded the contractor William Brady to support the scheme in September 1856. There is considerable doubt over the value of any of these surveys (Michler, 1861).

De LESSEPS SCHEME

There is no intention here to dwell on the history of de Lesseps scheme. Suffice it to say that the successful completion of the Suez Canal gave him credibility both in France and internationally, and meant that his call for an International Conference to discuss an Atlantic-Pacific Ship Canal could attract serious British engineering attention.

(Sir) John Hawkshaw among 6 British engineers, was invited to attend the International Congress in Paris in 1879. The proposal for a sea level canal at that time involved a tunnel through Culebra, which Hawkshaw had rejected as impractical. He had identified the control of the Chagres river as a key to success, and believed the proposal would not achieve that. His son, John Clarke Hawkshaw, had attended that meeting as a young engineer, and believed that the key to the success for the French scheme of the 1890s would be control of the waters of the Chagres.

Soon after construction began, in 1884, John Lewis Felix Target (Cross-Rudkin and Chrimes, 2008) was asked by the Governor of Jamaica to report on the conditions of the Jamaican workforce. This brought him to the notice of the Anglo-Dutch contracting consortium who had been awarded the contract for the Culebra Cut. He acted as their consulting engineer for three years until ill-health obliged him to give up – allegedly the climate inflamed his gout.

CULEBRA CUT AND THE ANGLO-DUTCH CONSORTIUM

The Anglo-Dutch consortium who began work on one of the toughest sections of the Panama Canal comprised a London based grouping of Cutbill, Son and De