Wrong Way

Literary Club 11/13/06

By David Black

The Thames

It was my first[1] trip to London. We had decided to go on our own, not with a group that would make all our plans for us. In a mild attempt to keep expenses low, we bought 7-day passes on the Underground to avoid taxi fares. So we did our own planning with a Dorling Kindersley [DK] guide book, a map of the Underground, tube passes embellished with our passport pictures, and 2 umbrellas.

My wife had been to London many times before, and had visited most of the art museums. But on this trip she particularly wanted to see the new Tate Modern, opened in 2000. So by bus from our borrowed flat in Chelsea we negotiated bus and subway to Blackfriars Station, and walked across Blackfriars Bridge over to the south side of the Thames River in a drizzle. At the top of the stairs leading to the bankside level, a gust of wind blew our 'brellies inside out; and we hustled into the Tate.

After seeing some of the Picasso's, Dali's, and Warhol's, we found the cafe and sat down for a light lunch. It was there that I saw it through a huge window – the river was flowing from right to left! "That can't be," I thought. " We're on the south side of an ancient river that goes from the West in an Easterly direction to the sea" The Thames was going the wrong way! And not slowly. Now I don't know much about modern art, but I do know that rivers flow down to the sea. "Could it be that, coming out of the Underground, I got turned around, and confused, and the Tate was really on the North bank? Or that the twisting and turning of the Thames had turned it away from the sea for a short distance?"

So I began asking some questions of the natives: museum staff, bobbies, headwaiters, and finally a riverboat captain. I learned that the Thames is a tidal river, that the water does flow backwards twice a day with the flood tide, at a rate of some 5 knots[2]. The tide affects the flow all the way West to the Teddington dam at the London borough of Richmond, about 11 miles upstream from London. Even more astonishing to me is that the range of the tide[3] at London, i.e. the <u>average</u> height of the spring tide rises, is about 7 meters or 22 feet: and the maximum range is 24.6 feet. That is 2 stories!

A bit more research in the DK travel guide and the Encyclopedia Britannica revealed that about 8 miles below London, 2 miles below Greenwich, is an engineering marvel called the Thames Barrier. It was completed in 1982, 3 decades after the storm surge of 1953 flooded some areas around the Thames and drowned 300 people. It was designed to control the upstream flow of the water when necessary, without obstructing river traffic during normal tides and normal weather.

I had to see that. Stretching across the river, there are 9 upright piers[4], between which 8 semi-circular drums are pivoted. Normally these drums are rotated down, so that they each sit in a semi-circular bed at the river bottom. Boats can pass between the upright piers and over the drums. When they are rotated up 90^{0}, they block the rise of the tide and any storm surge. Since the Literary Club's Rules of Engagement forbid visual aids, let me try a second time to help you visualize how the Thames barrier gates work.

Imagine a long, solid cylinder from south to north across the river[5]. Slice away, horizontally, 80% of it, leaving three solid parts of the original cylinder. The largest part is shaped like a shallow letter "D", when seen in cross section from the south. It is resting on the rounded part of the "D". The other two solid parts are untouched slices of the original cylinder, shaped like wheels on the extreme ends of the mutilated cylinder. The "D" is attached to these wheels. The "D" rests on a metal bed which has the same curvature as the "D". In cross section the straight part of the "D" is a flat, some 19 feet under the water at lowest tide[6], so that boats with 15 foot draft can pass over it. When a dangerous surge is predicted, the "D" is rotated 90^{0} counter-clockwise so that it looks like a proper "D", properly upright, its bottom touching the metal bed on the bottom, and blocking the flow of both tide and surge.

Whether I have helped you, or lost you, it works in real life. The barrier has been employed several times a year since it was finished. In the 21st Century it is predicted to be used up to 10 times a year[7]-- to protect the City of London from flooding.

London flooding! Oh, my lord; what would happen if the brackish water went over the riverbanks? The subway tunnels would flood, building foundations would weaken, sewers and gas and water and electricity mains would be paralyzed. London would get a more crippling shock than Katrina gave New Orleans! So the Thames Barrier is an important hunk of hardware.

The threat of flooding London focused the minds of the Brits in 1953, when a storm surge tide[8] rose 9" higher than the previous high in 1928. That one had exceeded the previous record of 1881 by a foot, and it had overflowed the Teddington dam, 11 miles upstream. In 1953 the parapets defending the Houses of Parliament were threatened. Understand that this represents increasing high water marks: in fact the highs have increased by 4' over 160 years. Why?

There are 5 reasons.

First, the growth of the City required more bridges, then larger piers for heavier traffic, thus the narrowing of the navigable river. This has required the flowing water to move faster, and scour a deeper channel, which lets the flood tide move faster and, by momentum, rise higher.

Second, it is estimated that the melting of the polar ice caps has raised water levels about half a foot per century. Third, due to tectonic plate movement, the northern land of Britain is rising, and the southern half is sinking – about 2 mm per year[9] or 3¼ feet per century. Fourth, over-pumping groundwater to quench the thirst of people and industry, has caused a sinking of the land that supports river walls. Fifth, the silting up of the Thames Estuary has raised the floor of the mouth of the river.

On a personal note, I experienced a negative effect of a big tidal range as a teenager. I had sailed as the guest of a college roommate, Ken Williams, down East, across the Bay of Fundy, to Digby, Nova Scotia. Ken's dad was an insurance company lawyer. That was lucrative enough for him to own a 40 foot cutter. Mrs. Williams was an indifferent sailor, but she was a fine cook. When we tied up at the float in Digby, she announced that she wanted to eat ashore. None of us males wanted to take over the galley, so we disembarked. Mrs. Williams had to climb up a wet and somewhat barnacled ladder, and that took a lot of encouragement. Dinner over, we came back to the sailboat. But the tide had gone out, and the second spreader was about level with the dock, meaning a roughly 40 foot climb down the wet and somewhat barnacled ladder. "No thanks," said she. "I'll sleep ashore tonight." I found a ramp going down to the float to which the cutter was tied, and persuaded her to have a look at it. "See," said I, "There are small steps going down near the handrail. You grab the handrail with one hand and put the other on my shoulder, and we'll walk down together." More persuasion, and we started down. All was well, until ¾ of the way down, the steps on my side were no more. The ramp was oily and I traveled the rest of the way down, without Mrs. Williams, on my ass. Humiliating for a Princeton sophomore. But it taught me a bit about tidal ranges and their threats.

You are undoubtedly aware that so called "spring" tides have nothing to do with a season of the year. The word is derived from Old English, *springen*, meaning *to rise up*. They occur throughout the year when the sun, and earth, and the moon are aligned. Newton's Universal Law of Gravitation says that the mutual attraction of any 2 bodies is directly proportional to the product of their masses, but inversely proportional to the square of the distance between them. This means that the moon, being closer to earth, has almost twice[10] the effect on ocean waters than the far more distant sun.

But the largest threat to London is due to a surge on top of a spring tide. Ocean surges occur because of wind storms, in the North Sea. A big atmospheric low near Newfoundland[11] will move across the Atlantic toward Europe. The low pressure raises the water in a hump, perhaps a foot high, and it travels eastward at 40-50 mph. As it moves over shallower water, the hump rises in height. When it is driven south by a northerly gale, the hump is raised further not only by the wind but also by the funnel effect of the narrowing coastlines of England and the continent. Storm surges have raised the water at the mouth of the Thames by as much as 8 ½ feet, and by 14 feet on a rising tide. If protective walls were designed only for the 24.6 foot spring tides, the infrequent, but occasional, storm surge on top of a spring tide could produce disaster.

So after the storm surge and flood of 1953 left 300 dead and much damage around London, the British government had to address the threats of future flooding, while being mindful the fiscal necessity of keeping the Port of London open for ocean trade, so that England could work its way out of the monumental debts of World War II.

Over the next 21 years several prestigious committees dealt with a range of problems in trying to arrive at a final design.

- Should the surge be stopped by a large dam with locks for river traffic, or by a barrier whose gates could be raised and lowered? Many alternative designs were submitted before the barrier design was chosen.
- Where should the device be located on the Thames? Two other alternatives further downstream from London were proposed before the final choice was made.
- How wide should locks or gates be designed for river traffic to pass by or through?
- How do you estimate the height of future surges, when the history is infrequent, at random intervals, and rising? The final choice was based on 1] a probability analysis of an occurrence every 1000 years, and 2] the historical trend of surges.
- What will it cost? How can you get firm bids on a project that will last 4+ years, during which the pound is depreciating in value? It did depreciate at almost 8% per year. And the cost inflated from Lb 111 million to a final cost[12] of Lb 440 million. At today's exchange rate, that is about $0.8 billion.

- Who is going to make the decisions about these imponderables? At least three different committees, and many government departments, wrestled with the issues.
- Can the design selected be constructed before the next surge threatens London? In fact, surges at the beginning and at the end of 1978 came within a foot of the 1953 disaster height.

The major contract for the 9 piers, the abutments, and the 8 gates was signed in July 1974. Completion, determined by the first full closure of the gates, was in November 1982, over 8 years later.

The Delta Works

On a later trip to Europe, I came across another approach to prevent the flooding of storm surges.

The North Atlantic storm of 1953 that led 30 years later to the Thames Barrier, also damaged the southwestern portion of the Netherlands and killed 1,835 Dutch people[13]. In 1958 the Netherlands Parliament passed the Delta Act, and it led to a massive endeavor called the Delta Project, which took 25 years to complete.

The Dutch had a somewhat more complicated problem to solve. Although the average spring tidal ranges there average about 16 ½ feet, versus London's 21 ¾ feet, the problem of harnessing the sea is more difficult. Three major rivers empty into the sea: the Rhine, the Maas [or Meuse], and the Scheldt. The latter splits into an Eastern part, and a Western part which leads to the harbor in Antwerp. All of this river water forms a massive delta, about 41 linear miles across the river mouths and delta islands. To prevent storm surge flooding of the precious nether lands within that delta, a series of dams and flood walls had to be designed and constructed. Not only did the Western Scheldt need to be kept open for traffic to Belgium's Antwerp, but also ocean traffic needed to be maintained to Rotterdam, at the northeast corner of the delta region.

The original plan called for 10 dams[14], but eventually were added -- a dam, a discharge channel, and a storm surge barrier in 1997 to protect Rotterdam[15]. The final cost of the original 10 dam plan was Fl 12 billion. I calculate this, to be a magnitude of $7 billion, roughly 10 times London's outlay. Very little of this is offset by the savings in raising the heights of dikes less high or fewer of them.

The construction of the first 9 dams is unique and remarkable, but I don't believe that we have the time or the patience. The final dam on the Eastern

Scheldt, however, is interesting. A] It is not a dam, and B] it absorbed 2/3 the money spent.

Instead of a dam which would stop the semi-diurnal tides and ruin the marshlands, the Dutch fishermen, ecologists, and eventually Parliament changed the plan to a storm surge barrier. They had seen the 1932 Barrier Dam built across the Zuyder Zee [now called the Ijsselmeer] in northern Holland provide for more polders [dried out marshes] and a great deal of new farmland; but they were also aware of the harm done to the ecology and the damage to the fishing industry. With the first dams in the Delta Project doing the same destructive things, they began to reconsider the plan during the period of increasing environmental awareness of the late 1960's. By the end of 1973, 5 km of the Scheldt Dams had been completed: 3 km remained to be finished. The government commissioned a study, and its 1974 report recommended a storm surge barrier that would allow normal tides not to alter the rich environment in the Eastern Scheldt. It is home for 75 species of fish, including sole, cod, herring, gar and anchovies. Also mussels, oysters, snails, sea acorns, sponges, varieties of seaweed. A great feeding ground for birds[16]. Parliament succumbed to the change of plans in mid-1976.

> *Wrong Way*. In its self-examination report of 6,113 pages last June [2006] the Army Corps of Engineers admitted that it waffled on the original plan to build "large barriers at the openings between Lake Ponchartrain and the Gulf of Mexico. Environmental groups complained and filed suit...Local levee, sewerage, and water boards objected to flood gates..."[17]. The Corps backed off, instead of working out a compromise.

The Dutch barrier design called for 65 concrete piers and 62 vertical steel gates, which could be lowered between the piers when a storm surge threatened. This was expected to happen only a few times a year, but the overall protection of the Delta Project was to handle minor flooding every 4000 years, and a disaster once in 10,000 years[18].

> *Wrong Way*. Our Army Corps admitted it had "designed a system to protect New Orleans against a relatively low-strength [category 3] hurricane...and did not respond to warnings from the National Oceanographic and Atmospheric Administration that a stronger hurricane should have been the standard." [17]

The Dutch genius for hydraulic engineering was challenged in the detail design and construction of the Scheldt Barrier. The bottom of the estuary had to be prepared for the weight of the piers and gates. River deltas are not hard, so the riverbed had to be compacted to a depth of 50 feet [15 meters]. That took 3 years and a specially designed vessel. On top of that was laid a

14" thick mattress of polypropylene filled with graded layers of gravel, made in a factory on a work island in the middle of the estuary. It was rolled onto a floating drum and was laid on the bottom with another special vessel. Then a second mattress, much like the first, was laid on top of it. With other materials and procedures, too detailed to hold your interest, a proper bed for the 65 piers was constructed "more level than most football pitches[19]". And this had to be done during the one hour of slack water at high and low tides.

> *Wrong Way*. The Army Corps "failed to take into account the tendency of local soil to sink over time." In fact "a 400' section in Plaquemine's Parish, south of New Orleans, shifted [last spring] as it neared completion. The marshy soil ...could not support the weight of the earthen levee structure, which slumped and bulged." [17]

The Delta Project piers are enormous. They are 98' to 131' tall, so that on a river bottom that varies across its width the tops will be level; and they weigh up to 20,000 tons [18,000 mt]. Construction time for a pier was 1½ years. It took specially designed vessels to transport and to lower each pier precisely in its location. One vessel picked up, transported and lowered the pier onto the mattresses just described. A second vessel moored itself accurately and securely, attached itself to the first, and positioned the first for proper placement of the pier. Again, there is more detail to the grounding of each pier than you need to know to be assured that they are intended to stay in place, in spite of the scouring and erosion that might be caused by the semi-diurnal flow of tides, and to last for 200 years.

Between each pair of the piers there are 2 horizontal so-called sill beams. The lower one rests on the river bottom; the upper one is toward the top of the pier and forms the top bearing surface for the gate when it is in the closed position. The steel gates have a span of about 138 feet between the piers. They vary from 19' to 39' in height, to accommodate the dished river bottom. They are box shaped in cross section. When lowered from their normal UP position, which allows the tides to have their way, they seal against the sills. Hydraulic apparatus on top of the piers does the heavy lifting. Also on top of the piers is a roadway, for regular traffic and tour buses, like the one I took.

Control of the gates is centralized in a building raised high on the construction island. That center also houses the weather, tide, and wind forecasting that was needed during construction. Currently the barrier is closed about twice a year. It takes about an hour to close the highest gate.

<u>La Rance R., St. Malo, France</u>

Regarding both the Thames Barrier and the Delta Project, a lot of money and energy was spent on defending valuable land that is periodically threatened by high tides and storm surges. One wonders whether more pro-active measures might be employed to harness all this natural energy. Of course!

FDR, as you will recall, had a notion to harness the enormous semi-diurnal tides in the Bay of Fundy, that unique area where I took my pratfall trying to help Mrs. Williams. At Minas Basin, in the far northeast area of the Bay, the average spring tide range is 43.6'. Two sites here have the potential of generating 333 megawatts of power[20]. I'm not sure exactly what scuttled FDR's idea: perhaps the costs of WW II prohibited further spending; perhaps the fact that we don't own the Bay of Fundy.

The next largest tidal range is at the Severn River, near Bristol, England: 40.3'. For comparison, London Bridge is 21.7'. The grandest proposal of all is an 8640 megawatt[21] facility on the Severn, which has the potential to provide 12% of the UK's requirements. The proposal was shelved in 1987 due to economic problems.

However, there is an operating tidal generating plant, in France. On the English Channel coast, between the Normandy and Brittany peninsulas, on the estuary of the La Rance River, near St. Malo, 24 turbine-generators, mounted horizontally under a dam, produce 240 megawatts – enough to serve 1500 homes for a year[22]. It has been tied in to the French national power grid for the past 39 years, since de Gaulle inaugurated it in 1967[23]. It employs an average tidal range of 26', and uses both the flood and ebb tides. It took 3 years to build, and cost $680 million. Not only has that cost been recovered, but its production costs are lower than for nuclear electric power generation [18 E cents per kwh, versus 25 E cents][24].

There is a second tidal generating plant at Annapolis Royal in Nova Scotia's Bay of Fundy. It has been operating since 1984[25]. It is much smaller than St. Malo, generating 20 mw with a single turbine. A tidal plant further north in the Bay of Fundy, at the Minas basin, could use currents which exceed 8 knots, and whose volume is 117 times the flow volume of La Rance. At mid tide "it equals the combined flow of all the streams and rivers of the earth (about 4 cubic km/hr)"[26].

<u>Considerations About Tidal Power</u>

The attraction of tidal power generation is obvious: a no cost energy source to run the turbines. There are about two dozen locations around the world that might have the tidal ranges and upstream basin areas to consider further study for tidal power generation[27]. Canada has 3 more possibilities. Russia has 2, and the US has one in the Cook inlet in Alaska. But there are several concerns and disadvantages to the method of damming up a river as France did.

The initial cost can be considerably higher than a conventional power plant. Tidal power has to be considered a supplement to existing power grids because the force of the tide varies through the 25-hour lunar day, so the power generated would be variable.

In order to capture the tidal waters, you have to close off the gorge or river through which the water flows. That requires locks, if river traffic is to be maintained. And the large pool area upstream from the generators, which has to be large to make the project feasible, will have its ecology changed. Fish migration is impeded, and the upstream ecology is altered. The Severn River proposal would create a 1300 sq. mi. pond behind it that would stop up the waste created in central England, and thus form the world's most offensive cesspool[28]. Lastly, there is arguably a chance that high tides downstream might be raised to unacceptable levels.

Other Methods of Generation

Rather than use the height of the tidal range with a dam and horizontal generators, another approach is to use the velocity of the tidal movement. You have probably all seen groups of propeller driven turbines, mounted in areas of high winds. Similar propellers mounted underwater in tidal currents of 4 to 6 knots can generate electricity. Norway is experimenting with a single tidal turbine which generates 300 kw in a current of 5 knots.[29]

Finally, an entrepreneur in Scotland, Max Carcas, is experimenting with snake-like, floating tubes, the size of a passenger train, 492' long, 11.5' in diameter, which are moored at a right angle to ocean waves. As they undulate and sway with the waves, three hydraulic rams mounted along their length are pumped, drive hydraulic motors which turn electrical generators. Arrays of these devices, called Pelamis, are being tested in the Orkney Islands, Hawaii, Western Australia, and New Jersey[30].

As the price of oil rises, I am sure that there will be more ingenuity focused on using the no-cost energy of water flow and undulation, and tidal ranges to generate electrical energy, thereby getting something for little or nothing in operating costs. That will be **the right way** to use water flows.

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Endnotes

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1 Personal chronology is altered to fit the outline of the paper
2 TB page 32
3 TT Europe, page 164
4 EB, and TB page 96
5 TB page 82
6 e-mail from Port of London Authority
7 TB page 138
8 TB page 4

9 TB page 11
10 TT page x
11 TB page 14
12 TB page 123
13 SSB page 3
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30 NYT 8/3/06