Engineers of our own Disaster: Dike Construction, Land Reclamation, and their Hidden Consequences

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It was as a freshman in high school that I first realized a career in science might be in my future. Up until this point, I had secretly fantasized of some sort of career in professional sports. However, my athletic talents argued against such a pipe dream. A short, scrawny kid with no curveball simply wasn't going to make the big leagues. But, such limitations didn't apply to a future in science. Soon after I realized that my passion for fossils was actually a calling, I left baseball behind in exchange for long nights of reading about dinosaurs, woolly mammoths, and mass extinctions. Not wanting to give up sports entirely, I joined my high school tennis team, despite the fact that I had never played tennis before. By any admission I was a lousy player, but by this point I really didn't care. Fossils had consumed me in a way that even baseball never did, and I was well on my way to what I hope is a lifetime of studying geology and evolution.

At the time, however, I was still a mediocre tennis player, and mediocre tennis players need lots of extra practice. Every day after school my team would hold two-hour practices, which for me were often torturous. But, even though I had given up my fantasies of succeeding as a professional athlete, I wanted to give tennis as much effort as I could. Thus, every day I ran out to the practice courts as soon as school ended, which bought me another twenty minutes or so of practice time. Before long, however, my enthusiasm for extra work had worn off, and I began to replace that added practice with a short walk around the tennis courts.

By a chance coincidence, my high school was built along the very spot where the Illinois and Fox Rivers meet, which afforded nature buffs such as myself a prime opportunity for bird watching, insect collection, or just general contemplation. The decision to build my school near the intersection of the two rivers also had its downside.

Every year, almost predictably, a series of spring floods would drown the first floor of the school in several inches of muddy, slimy water. One such flood, which still constitutes the record flood stage for the Illinois River, dumped some eight feet of water in the school's basement, canceling classes for several weeks and necessitating a prolonged period of cleanup, in which mud and other debris carried by the river had to be washed from the walls, ceilings, and floors. Finally, after several years of annual deluges such as these, the State of Illinois decided to construct a massive levee to protect the school from floodwaters. This levee was built midway during my freshman year of high school, and soon after its completion I began making daily walks across it before tennis practice began. I quickly learned to appreciate just how important and effective the levee was in protecting my school. At the same time, I also started noticing how the structure was gradually changing the local environment, largely by altering patterns of vegetation and changing the direction and speed of river currents.

In the six years since the levee was built, my high school has enjoyed complete protection from river floods. In fact, younger students currently attending the school, such as my brother, have little appreciation for the past floods. They simply take the levee for granted, seeing it as a big, hulking structure that keeps water off of the playing fields and out of the classrooms. What they don't understand is that levee construction has further consequences besides preventing flooding. However, the younger students should take consolation in the fact that societies are just now awakening to the reality that building levees, seawalls, and dikes has unforeseen and often counterproductive drawbacks. Despite over a millennium of such construction projects, only today are engineers and geologists beginning to realize that by holding floodwaters back they are driving forward land erosion, environmental destruction, and even flood energy itself.

The annual Illinois River floods that so frequently submerged my high school were bothersome and frustrating, but not truly devastating. Piles of river driftwood could easily be removed from the football field, mud could be scraped from the walls, and the water itself was usually quickly drained from the classrooms. In this sense, my high school was lucky. Often times, floods are known to be incredibly damaging, and in no place is this more true than in the Netherlands.

As a flat-lying coastal nation subject to monstrous tides and frequent storms, the Netherlands is constantly battered by destructive floods that rush in from the sea at nary a second's notice. Residents of the Netherlands have been dealing with these floods for well over a thousand years, and as early as the 9th century several cunning early settlers devised an ingenious defense against them. By building simple seawalls, these Dutch colonists could protect their farmland and dwellings from the frequent flood waters. Such a system proved so effective that within a century these protective constructions began popping up everywhere. Before long, the dike evolved from a purely defensive structure into a potent offensive weapon that was used not only to keep floodwaters out, but also to actively reclaim tidal land and peat bogs for use in farming. What the Dutch didn't know is that the dual practices of dike construction and land reclamation result in several negative and often counterproductive consequences. Due to its long history of reclamation projects, the Netherlands provides a perfect test case for assessing the pros and cons of dike construction, and has given many geologists and engineers a deeper insight into the basic consequences of such widespread and ubiquitous practices. Such an understanding of the fundamental science behind water defenses is critical today, as an increase in population density is pressuring many nations to consider new defense and land reclamation techniques.

In its natural state, much of the land that comprises the Netherlands is poorly suited for agriculture and human occupation. Areas near the Dutch coast are in constant danger of the aforementioned floods, and safer, more inland areas are often littered with peat bogs and marshes, which reduce arable and habitable land to isolated patches. It also doesn't help that much of the Netherlands is below sea level, and underlain by recently-deposited sediments that are neither consolidated into firm rock nor rich in nutrients. In spite of these limitations, population pressure in Medieval Europe drove waves of settlers into the Dutch lowlands. But, as destructive floods are frequent in the Netherlands, these inhabitants were soon faced with a harsh reality: devise some sort of protection or lose valuable land. Hence the invention and subsequent evolution of the dike, a process of experimentation and construction that is well chronicled in Dutch historical records.

Based on these records, historians have learned that the first dikes were constructed in the 9th century, but these were chiefly smaller structures utilized by individuals to protect their own private land. A little over a century later, however, larger-scale constructions were inaugurated, largely in response to a series of disastrous floods that destroyed much farmland and claimed thousands of lives. Shortly after these storm events, the Dutch began to reclaim large tracts of peat bogs, which they converted into farmland to replace the land lost to the floods. This process was simply accomplished by pumping water out of the bogs, and then planting crops shortly afterwards. However, since this newly-created land was located near the sea, and thus prone to severe floods, more sophisticated water defenses were needed to protect the reclaimed peat bogs. As a result, larger dikes were built, often as communal public-works projects. These first dikes were purely defensive in nature, rarely more than 1.5 meters high and meant to protect the reclaimed lands from both floods and high spring tides.

Over time, however, the dike metamorphosed from a protective structure into a construction aggressively used in land reclamation. This new function for the dike was enabled by the invention of the sluice, a floodgate that closes automatically at floods and draws in at ebbs, thus facilitating the deposition of sediment. After two or three yearly cycles, enough sediment is deposited by this method to create a tract of dry land. At this point artificial drainage is introduced, as ground water needs to be constantly pumped to prevent the new land from becoming too moist for agriculture. Although improved upon over time, this basic practice continues today, and its most spectacular result has been the creation of several thousand square kilometers of new farmland over the past millennium.

While the Dutch quickly figured out how to build dikes and use them to both protect and reclaim land, what they didn't understand were the side effects of this practice. Back in the 1100s the modern science of geology was still a good 600 years from being invented, and thus the Dutch knew little about tidal flat sedimentology or the hydrodynamics of ocean currents. However, in the years following a binge of dike construction in the 12th century, the early settlers were sure to notice a prolonged period of intense floods, one of which claimed some 50,000 lives. It is also likely that these settlers began to realize that their newly-created farmland was often moist and lacking nutrients, and thus poorly suited for their crops. It is unknown whether these early Dutch tribes made any causal connection between these new predicaments and their construction of dikes. But, with the benefit of hindsight, we now know that severe flooding and poor farmland are both direct consequences of dike construction and land reclamation, along with a slew of other highly negative and often disastrous side effects.

First and foremost, dikes alter the motion of ocean currents and the deposition of sediment. Normally, nearshore ocean currents flow perpendicular to the coast, as can be seen by observing waves breaking on a beach. In doing so, these currents deposit sediment and nutrients. However, detailed studies of dikes have clearly shown that the presence of these massive constructions strongly affects the direction and intensity of currents. Instead of moving perpendicular to the shore, currents near a dike are diverted, and flow parallel to the shore. Because of this seemingly minor difference, any sediment or nutrients carried by the currents move along the shore, and little direct sediment deposition occurs. As a result, areas downcurrent of a dike are starved of sediment, and without this source these lands quickly begin to erode. In fact, the study of one modern dike shows areas downcurrent to be eroding at the astounding rate of 10 cm/year. Of course, such erosion is completely counterproductive to the entire process of protection and land reclamation.

Additionally, modern studies have also shown dikes to increase the intensity of ocean currents. In doing so, the dikes effectively amplify the energy of storm floods. If the dikes are constructed well enough, they should be able to withstand the heightened floods. However, in the case that a dike bursts, the floods will actually be more destructive than if there was no dike at all. This fact is thought to explain the aforementioned 1287 flood that took 50,000 lives and destroyed widespread areas of farmland. It is foolish to think that such an event could not happen today, especially given that several hundred more dikes currently parallel the Dutch coast than during the 12^{th} and 13^{th} centuries.

While dikes themselves dramatically affect the local environment, the process of using dikes to reclaim land also has several negative consequences. When peat bogs or tidal flats are reclaimed, the sediments making up the new land will compact under their own weight and eventually dry, which enables easy erosion by winds. Coupled with the continuous artificial drainage needed to keep the land dry enough for agriculture, compaction and erosion leads to subsidence, a lowering of the land level which has two major drawbacks. First, subsidence causes the ground surface to approach the water table, increasing the moisture content of the soil and threatening the utility of the land for farming. Secondly, continued subsidence lowers the land surface to such a degree that if dikes protecting the area happen to burst, removing floodwaters is often impossible. Obviously, both effects are entirely negative, and extremely counterproductive to the desired purpose of land reclamations: to create new land to use for farming.

Even if subsidence and flooding are avoided, the newly-created land still may not be ideal for raising crops. First, the presence of dikes and their effects on ocean currents prevent the deposition of nutrients on land, which are vital in maintaining a rich soil. In addition, reclamation of tidal areas promotes oxidation and desalination of sediments, which has been shown to produce a surface-crust with strikingly different chemical and physical properties from surrounding soil horizons. Heavily oxidized and strongly acidic, this crust is not well-suited for farming. Thus, with a soil poor in nutrients but rich in a chemically-altered crust, land that is reclaimed for the distinct purpose of farming is often unable to sustain any crops.

Dike construction and land reclamation also raise several critical engineering issues. Most reclaimed tidal flats and peat bogs are underlain by soft and unstable sediments, which usually are not compacted into solid rock. By their very nature these sediments are unsuitable for supporting homes or other buildings, which necessitates precise engineering techniques for those wishing to build on such land. The weak properties of these sediments also complicate the construction of dikes themselves. Dikes are normally erected along the shore, where sediments are often softest and least compacted. Therefore, in order to prevent dike collapse, unconsolidated sediments must either be removed or artificially compacted. In recent years, this has resulted in the widespread use of "soft dikes," structures composed of offshore sands placed in front of the coast and shaped by winds into a semi-natural coastal "dune." However, if soft dikes are placed too close to tidal channels, underwater currents may penetrate the soft sediment of the dike, which leads to collapse. As has been shown, such a collapse will result in stronger floods, which are absolutely fatal to the mission of land reclamation.

The above examples constitute only a few illustrations of the largely negative consequences of dike construction and land reclamation. While dikes do largely succeed in protecting vulnerable areas from floods, these structures also result in more subtle difficulties that can heighten destruction. Ironically, the greatest danger posed by dikes and land reclamation is the increasing loss of arable and habitable land. Although dikes, levies, and seawalls are explicitly constructed to defend lands from flooding, they also alter currents and cut off sediment deposition, and in doing so actually increase the strength and destructive power of storms. If a dike happens to burst, these more powerful storms are more prone to flood reclaimed inland areas, especially considering that the reclamation process causes these lands to rapidly subside. Even if these reclaimed lands are not flooded, however, the rapid subsidence, along with alterations in soil chemistry and a lack of nutrients, often make them unsuitable for agriculture, the very purpose for which they were reclaimed. And, for those lands reclaimed solely for housing or other construction, the unconsolidated nature of most reclaimed lands results in many engineering complications.

Strolling along my high school's levee before tennis practice, these issues never crossed my mind. For me, and for so many people who have grown up alongside levees, dikes, and seawalls, these structures simply hold back the floodwaters and keep us safe and dry. Only after a more formal training in geology did I stop taking water defenses for granted, and start weighing the pros and cons of their construction. My quaint hometown, nestled among the farmlands of north central Illinois, uses levees only as defensive structures, with the sole purpose of protecting against floods. No complex Dutch-style land reclamation is practiced. However, even the use of levees as defensive structures must be carefully considered, as these constructions will modify currents, change sedimentation, and often alter the local environment. During my youthful strolls I saw some of these changes first-hand. Soon after the levee was constructed I noticed a new river channel forming parallel to seawall, and over time I watched as the distinctive marsh vegetation that characterized the riverbanks for so long disappear without a trace. Gone too were many of the unique birds and insects that made my nature walks along the river in pre-levee days so enjoyable.

But while my hometown and others faced with river floods must carefully weigh the construction of levees, a more critical and immediate conundrum is faced by countries such as the Netherlands, Germany, and South Korea, which have historically reclaimed vast tracts of land for farming and human habitation. With increasing population density, pressure is mounting for these governments to reclaim more land. But, what the public usually doesn't know is that such land reclamation has consequences that are too dire to be ignored. As with any policy decision, these governments would be wise to learn from the successes, and the clear failures, of the past. If not, modern societies risk increased loss of land and heightened flood destruction, which could be devastating environmentally, economically, and on a more personal, human scale.

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