UNIVERSITIES COUNCIL ON WATER RESOURCES
JOURNAL OF CONTEMPORARY WATER RESEARCH & EDUCATION
ISSUE 141, PAGES 1-16, MARCH 2009

Dutch Flood Policy Innovations for California

Dana L. Woodall and Jay R. Lund

Department of Civil and Environmental Engineering, University of California - Davis

Flood risk management is an important part of life in the Netherlands. The Netherlands is formed by the deltas of three rivers-the Scheldt (rain-fed, originating in southern Belgium), the Meuse (rain-fed, originating in northern France), and the Rhine (glacier and rain-fed, originating in Switzerland). The country also borders the North Sea, with the Scheldt River connecting the sea to Antwerp Harbor. The Rhine is the largest of the three rivers, splitting into three branches (the Ijssel, the Lek, and the Waal) as it crosses the border into the Netherlands (Tol et al. 2003). Two-thirds of the country lies below mean sea level (Voortman 2003).

The Dutch have a long history of attempting to control floods. As early as the ninth century, the Dutch started building dikes to protect reclaimed bog land (Kaijser 2002). These dikes started as local, individually-owned structures, but communities soon realized that closed dike rings were necessary to protect all sides of the region. These dike rings eventually became *waterschaps,* or "waterships," regional districts charged with water management including drainage and dike building. These districts are still the administrative body for flood defense (Voortman 2003). The 14th century saw the first major recorded floods in 1313 and 1315, leading to the famine from 1314-1317 that killed 5-10 percent of the population. Periodic flooding continued through much of the Netherlands' history. As sediment settled between the dikes, dikes grew taller. During the 19th century, reorganization of the water districts occurred and a national body was formed. Military engineers took over the construction and maintenance of the dike system (Tol and Langen 2000).

During the 20th century, as trained engineers and the central government took over flood control efforts, the analysis of appropriate techniques and construction increased. Prior to 1953 dikes were built to the height of the previously known high-water level plus a margin of safety (Jonkman et al. 2004). Following the catastrophic flood of 1953, the Delta Committee was formed to advise the government regarding flood control (Voortman 2003). One recommendation of the Committee was to establish an optimal exceedance frequency of the design water level based on risk of flooding and cost of protection. van Dantzig's 1956 paper described this risk-based calculation. He proposed that flood management required integration of three areas with noted problems: statistics, hydrology, and economics. In the past 50 years, significant effort has been devoted to expanding on van Dantzig's work and working on solutions to the problems he noted and the assumptions he made. Increased computing power, additional rainfall and hydrologic data, and watershed models have all added to the understanding of flooding while increased emergency preparedness and response have enhanced protection of land, homes, farms, businesses, and lives.

Northern California also has a history of devastating floods, although the history of floods and water management is much shorter than in the Netherlands. Throughout the past century and a half, winter rains and snowmelt have resulted in flood events that have caused billions of dollars in damage and multiple deaths. One of the largest floods in California history occurred in January, 1862 following four weeks of rain. No quantitative flows are known, but the banks of the Sacramento were breached and the water was, at minimum, three feet deep from Sutter's Fort to Davis (Harding 1960).

This flood also brought significant mining debris, covering the land near Marysville with one to six feet of sediment. During the second half of the 19th century, mining techniques had developed from ditch and flume operations to high powered hydraulic techniques that discharged up to a million gallons an hour from a single nozzle (Kelley 1989, Larson 1996). Over 1.5 billion cubic yards of sediment was discharged into the Feather, Yuba, Bear and American River basins from hydraulic mines (Larson 1996). However, the litigation between Woodruff and North Bloomfield Gravel Mining Company (1884) effectively stopped hydraulic mining by requiring complete containment of debris.

Early in the settlement of California, flood control was typically very local, with levees built by individuals or local governments. Following this major flood in 1862 and the resulting litigation, hydraulic mining ended and levee management moved to larger regional agencies and the state government.

The largest recorded flows in the Sacramento River were reached during the flood of March 1907. Although some tributaries have since exceeded their 1907 flows, the Sacramento River has not exceeded its peak flow of about 600,000 cubic feet per second (16,990 m^3/s) (Harding 1960). Thirty to forty inches of precipitation across Northern California during the week before Christmas in 1955 led to severe damages and levee failures. Seventy-four lives were lost and over $200 million in economic losses were attributed to the flood (Harding 1960). Record rainfalls led to major flooding in 1986. Levee breaks in the Sacramento River Basin led to 13 deaths and over $400 million in damages. Two of the most expensive floods in California's history (1995 and 1997) occurred within two years of each other and together caused nearly $4 billion in damages (Department of Water Resources website).

Early in California's history, no state or federal agencies managed flood control; flood control projects were managed locally. As settlement increased, however, state and federal funding and regional management became necessary. First, state and county agencies began acting to prevent flooding and then in 1917, federal authority for flood management was granted by Congress. Since then, there has been a fluctuating balance of power between regional and district, state, and federal flood control planning, funding, and management (Kelley 1989).

Six types of actions can be considered for flood management (Hoojier et al. 2004):

- Actions to prevent flood generation: land use management in the upstream basin,
- Actions to modify flood flows and elevations: flood storage, levees, bypasses, and channel improvements,
- Flood damage reduction actions: floodplain zoning, building codes, awareness raising,
- Preparatory actions: flood forecasting, warning and emergency plans,
- Flood event actions: crisis management, evacuation, and
- Post-flooding actions: aftercare, financial compensation, insurance.

The Dutch concentrated mostly on preventive flood control measures, and many of the measures implemented in California were first tested by the Dutch in their attempt to control flood waters. Some more recent Dutch innovations might increase California's ability to reduce flood damage. This paper is organized into three subjects. First is a review of Dutch flood control innovations. Next, implementation of each measure is discussed in California's context. The final section wraps up the discussion with a summary of key points and conclusions.

Dutch Flood Management

Flood Control Structures

Dutch flood defenses have three components: dunes, dikes, and special structures. Natural sea dunes protect coastal areas from tides and storm surges. The dunes are planted with helm grasses to hinder erosion. Where there are no dunes, the Dutch built dikes. The dikes, initially constructed along the river, have become dike rings to provide protection on all sides. The 1500 mile dike system in the Netherlands includes some massive engineering and construction accomplishments. The Afsluitdijk dike, for example, prevents North Sea intrusion into the Zuiderzee and has created the IJsselmeer freshwater lake. The dike is over 90 m wide and 32 km long. Cross dikes are used to protect against upstream dike bursts. An early example was constructed between the Lek and Linge rivers in 1284. Although this crossdike offered protection to those downstream, it increased the damage upstream (Tol and Langen 2000).

Special structures include the Maeslankering storm surge barrier that closes to protect Rotterdam and surrounding towns from flooding from abnormally large storm surges. Each of the two barrier "arms" is as tall as the Eiffel Tower if placed upright (Sayler 2006). Other special structures include cofferdams, gates, and retaining walls. In general, these special structures are in place as temporary solutions in response to a flood event or storm surge.

Risk-based versus Reliability-based Design

Flood management policies and system designs are established to reduce flood damages. Engineers today use two strategies to evaluate flood management solutions: risk-based and reliability-based design. These design strategies are described below.

Risk-based design focuses on minimizing the future costs of flooding by taking preventative measures today. Risk has two components- the chance an event will occur and the consequences of that event (Sayers et al. 2002). A subset of cost-benefit analysis, the optimal risk-based design results in the minimum total cost, from summing all costs multiplied by their probabilities for each alternative, and choosing the least expensive alternative. Risk-based design requires having a pre-established flood probability distribution, as well as reliable estimation of the damages from different flood levels. A discount rate is applied to future costs to give a net present value for evaluating different protection levels. A benefit of the risk-based approach is that it allows choices based on comparison of expected outcomes and costs of solution alternatives (Sayers et al. 2002, Hall et al. 2003, Vis et al. 2003).

Reliability-based design is based on a pre-established "acceptable" failure probability target. Legislation, insurance policies, or other parties may determine an acceptable failure probability based on different preferences regarding loss of life, infrastructure investment, or economic loss. Acceptable failure levels may be based on the previously discussed risk-based design using the failure rate with the best net present value for the flood protection system and probable damage during flood events. Reliability-based design allows engineers and planners to develop a solution set of alternatives that provide the target level of protection and then choose the lowest-cost alternative.

Flood protection systems can incorporate both methods. For example, risk-based design requires substantial data for a given floodplain. By evaluating just one section of that region with risk-based design, a target failure probability can be established and applied in a reliability-based approach to the entire region, provided other parts of the region have similar flood hydrologies, costs, flood damages, and benefits.

Currently the Dutch use a minimum acceptable flooding probability for flood protection. The reliability-based design standard is based on an economic optimal value, or risk-based evaluation. The safety standard for a dike ring protecting a heavily populated city and its suburbs is higher than the standard for a dike ring protecting agricultural land. This integrated method results in the reliability design standards summarized in Figure 1.

Resistance versus Resilience Strategies

Evaluation of risk- and reliability-based designs considers the two factors of flood risk: the frequency of flooding and the consequences of flooding. Resistance strategies are designed to reduce flood risk by reducing the frequency and magnitude of flood events. Historically, these are the most common and include dike or levee systems, and reservoirs and dams. Vis et al. 2003, list the following disadvantages to resistance strategies:

- design discharge is constant, resulting in the assumption that all areas and land use types have equal probability of flooding,
- inaccurate projections of economic development occur when a resistance strategy was designed decades ago, and
- continual maintenance and improvements reduce environmental habitat and spoil landscape qualities.

Figure 1. Dike Ring Reliability Standards (Flood Defence Act 1996)

Resilience strategies focus on minimizing the consequences of a flood. These strategies include allocating land as floodplains, developing better emergency response systems, and expediting flood clean-up and recovery. Often resilience strategies are described as ways of "living with the flood" instead of "fighting floods" (Vis et al. 2003). One disadvantage of resilience strategies is de-valuation of land due to rezoning for uses compatible with flooding.

Van Dantzig

In the 1950s, van Dantzig (1956) and the Delta Committee focused on three areas of flood management: statistics, hydrology and hydraulics, and economics. van Dantzig's approach involved risk-based design for a (mostly) resistance strategy. He was the first to approach flood defense design using probability-based quantitative cost-benefit analysis (Voortman. 2003). In evaluating the economic decision, van Dantzig made several assumptions:

- Critical dike height refers to the height at which the dike may break, but only describes the relationship between this height (H) and crown height (H_c) as $H < = H_c$,
- Dikes only fail by overtopping,
- Dike breaks are repaired immediately,
- Value of goods is stable in time relative to estimated national growth,
- Probability distribution of reaching critical dike height is stable in time once corrected for sinking dikes (no climate change),
- Value of ecological habitat (and other non-economic entities) is neglected, and
- Emergency response and evacuation capabilities are perfect with regards to human life.

Figure 2 illustrates van Dantzig's basic approach. The horizontal axis is the project size, or level of protection, and the vertical axis is the annualized cost of the project. The dotted line is the annualized installation cost which is the sum of annualized construction and maintenance costs; as the level of protection increases, so do these costs. The dashed line is the annual expected damage cost- as the level of protection increases, these costs decrease. The solid line is the total cost line and which is the sum of the two types of costs. The optimal risk-based design is the level of protection corresponding to the least total cost, or the lowest point on the curve.

Valuing Natural and Cultural Preservation

Within the Dutch river districts, the importance of preserving natural and cultural lands has historically received varying attention. In 1993, however, landscape, natural, and cultural-historical values were incorporated into national Dutch policy on dike improvements (Walker et al. 1994, Lenders et al. 1999). Since then, each river district has varyingly integrated these values into their dike reinforcement plans. Environmental Impact Assessments are compulsory for projects that are not classified as immediate and urgent (Lenders et al. 1999). Participation by local citizens and environmental groups is also encouraged.

Extended Life Quality Index (ELQI): combining economics and life expectancy

van Dantzig ignored the value of human life in his calculations for economic optimization. Nathwani et al. (1997) developed the Life Quality Index as a measure of the economic benefits of life expectancy. Voortman et al. (2002) used this to create the Extended Life Quality Index for evaluating flood protection decisions and for allowing human life to be included in mathematical and economic calculations for flood defense systems. However, the Extended Life Quality Index may be less important to total flood damage estimates when emergency alert and evacuation systems are included in flood defense measures. Currently, flood forecasting along the Rhine allows 2 to 3 days for evacuation and along the Muese forecasting is between 12 to 36 hours ahead of flooding (Hooijer et al. 2004).

Measuring and Managing Uncertainty

Uncertainty can contribute to flood management calculations in two ways- estimation of flood probability and estimating flood damages. Flood frequency estimates require knowing the probability and associated uncertainty of 1) hydraulic and hydrologic conditions, 2) failure modes of flood defense infrastructure, and 3) infrastructure failure and flood wave propagation (Kortenhaus and Oumeraci 2001). Expected damage is a function of economic development and hazard warning and preparedness (Sayers et al. 2002).

Hydrologic uncertainty is often due to lack of sufficient data for estimating flood frequency curves. Five statistical distributions are commonly used for flood frequency analysis: Generalized Extreme Value, Gumbel, Lognormal, Weibull, and

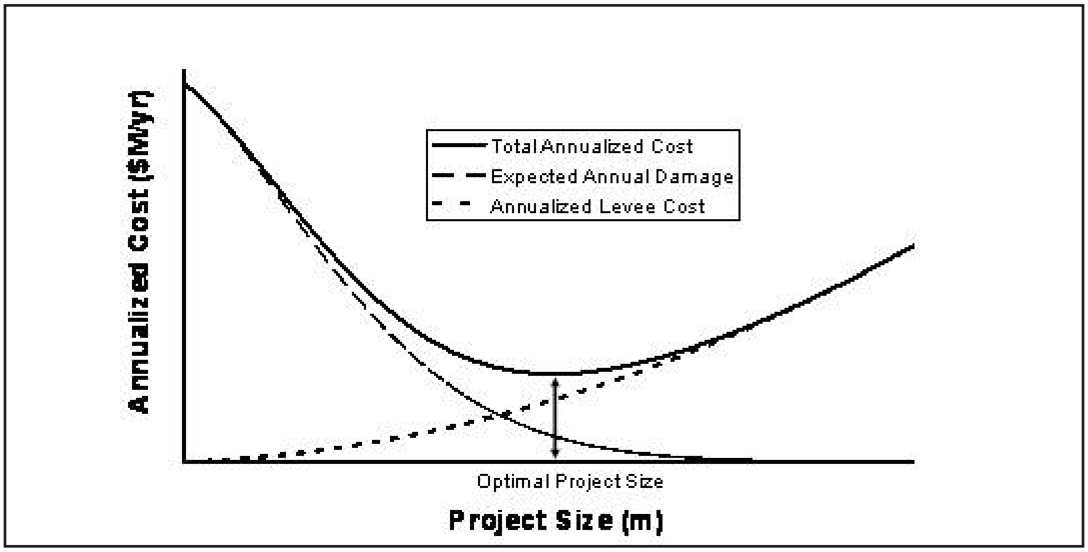

Figure 2. Example of Risk-Based Design

the Pearson-III (Singh and Strupczewski 2002, Apel et al. 2004). Using 35 years of data from the Rhine and Cologne Rivers, Apel et al. showed that the selection of distribution led to large variability (25 percent of maximum flood flow) in the estimate of the 150-year flood.

Failure of the dike system can be estimated based on failure mode. Voortman et al. (2002) list failure modes as internal erosion, breaching through inner slope via wave overtopping, overflowing, or uplifting inner revetment, and breaching through outer slope via failure of pitched block revetment. Each failure mode can be assigned a probability of failure. The combination of all failure modes can be used to estimate the overall probability of failure (Voortman 2003).

Once the defense system fails, flood wave propagation is important for estimating the extent of flood damage. Flood wave propagation can be a factor of the failure mechanism, the extent or length of original dike failure, and the characteristics of the flood hydrograph (Kortenhaus and Oumeraci 2001). Uncertainty can be reduced as better models for flood wave propagation are developed and the interactions of these factors are better understood.

As these different types of uncertainty are reduced through better models, more data, or further study, flood risk and damage calculations will improve. This will enable engineers and planners to more precisely evaluate flood protection systems and design alternatives.

Perception of Risk

Cost-benefit analysis requires economic quantification of all costs and consequences for a flood defense design. Because not all costs are easily defined in monetary terms, the bias of the decision-maker can be reflected in the analysis. Risk-prone decision making results in reported costs being lower than actual costs and benefits being valued more in the analysis. Risk-averse decision makers report higher costs and lower benefits than the flood defense system actually provides (Voortman 2003). Such bias is often unintentional.

An interesting aspect of flood management and risk assessment is how the public perceives risk and the importance of flood protection. Public perception of flood risk can affect budget, construction and maintenance of flood defense systems, and other aspects of flood risk management policy. There are three bases for public risk perception: dormant flood risk, immediate flood threat, and accidental/uncontrolled flooding (Baan and Klijn 2004). Dormant flood risk has two components- crisis effect and levee effect. Crisis effect occurs immediately after a disaster and causes people to overestimate future flood risk. Levee effect starts once protection measures have been taken and causes people to rely too heavily of the protection of the system and then grossly underestimate future flood risk (White 1945).

Immediate flood threat occurs during a flood event. As water height increases and comes close to the top of the dike, people feel emotions ranging from fear to inconvenience to solidarity (Baan and Klijn 2004). The degree of fear typically is inversely correlated to experience with flood events. People that live with frequent flooding typically experience less fear than those new to an area or living in an area that has not experienced flooding in several years. Past experience may be the single most important factor affecting people during high water levels. Those who have experienced minor flooding with little or no damage will underestimate the risk of damage. Those who have experienced loss of life or extensive property damage in the past are most likely to experience helplessness and fear (Burn 1999).

Evacuation is often perceived as more troublesome and threatening than the high water level (Baan and Klijn 2004). Those that require assistance from others to evacuate (elderly, children, disabled) are the most susceptible to negative feelings during high water events. Interestingly, even the forecast of a high water event may be enough to trigger these feelings. Not all feelings are negative. Feelings of solidarity or togetherness can occur among people who band together during a high water event.

The third base for risk perception is uncontrolled flooding. A flood event is linked to several negative effects ranging from premature death to feelings of ill-health and mental distress. These feelings typically fade as time passes after the flood event (Baan and Klijn 2004).

Public risk perception has been integrated into the Netherlands' flood strategy with specific regard to incorporating public involvement in decision-making. When the public is more involved and more educated in actual flood risk, negative feelings are reduced (Baan and Klijn 2004). Recent research indicates that people in the Netherlands no longer perceive flooding as a natural disaster, but instead as a failure of the flood management system (Baan and Klijn 2004). This has increased the likelihood that people overestimate the level of protection and place disproportionate trust in the man-made systems.

Financing Water and Flood Management

In the earliest days of dike building, landowners were responsible for protecting their property and making dike repairs. As cities formed, coordination among landowners was necessary, regional water authorities started to form. Maintenance costs were still distributed among land owners protected by the dikes and cities were mostly exempt from regular maintenance costs, but the *waterschappen* had authority to manage the construction, maintenance, and operation of dams, sluices, dikes and drainage canals (Tol and Langen 2000, Kaijser 2002). "Dike counts," *dijkgraaf*, were executives assigned to inspect dikes three times a year (spring, summer, and fall). The spring inspection identified repairs to be made; the summer inspection made sure that the work had been completed; the fall inspection was a final opportunity to identify problems before the winter. If a land owner was unable to fund repair costs, the dike count would loan the money at interest rates in excess of 100 - 200 percent (Tol and Langen 2000). For extensive repairs or following flood damage, the dike count could raise money by imposing a tax on cities. However, most of the financial burden fell on landowners and frequently these repair costs led to bankruptcy. Often dike counts abused this privilege and were able to amass large amounts of land (Tol and Langen 2000).

In 1798, a new constitution and more stable central government led to reorganization of a national budget and the formation of a national water authority (Tol and Langen 2000). The funding for flood protection comes from a combination of inhabitant and property taxes at state, provincial, and municipal levels of government. Provincial governments are responsible for implementing state water policies. Costs for flood protection may be covered by the national general budget, as long as they fit within the following activities:

- "Formulation of the national, strategic policy on flood protection and water management, supervision of its realization and enforcement,
- The realization of the operational tasks concerning the infrastructure,
- The flood protection works lacking hinterland or financial capacity; the Main Dike separating the Wadden Sea from the Lake IJssel, dams and barriers in the estuaries, dunes and dikes on the Wadden islands,
- The preservation of the coast by fighting the structural erosion,
- The operational management of the state waters. These waters concern the Rhine with its branches, the Meuse, the Scheldt, the Lake Ijssel, the estuaries, the principal canals and the territorial and international sea, and
- The promotion of the (inter)national shipping routes." (Huisman 2002: Page?).

In 1998 (the most recent year with published information), The Netherlands spent 1 percent of its national income (US $ 3.14 billion) on water management - 15 percent of which was for flood protection (US $ 444 million). In the next ten years, the Dutch anticipate spending $2.9 billion on flood protection (Woorden 2006).

The Water Board Bank (*Nederlandse Waterschapsbank*) was formed in 1954 when funding for the substantial repair work caused by the 1953 floods was difficult. The local water boards were too small on their own and formed the collaborative to allow long-term borrowing at favorable rates (Huisman 2002). The Water Board Bank is the fifth largest Dutch bank and is owned by public authorities (81 percent is held by the water boards with state and provincial government holding the remaining 19 percent) (Huisman 2002).

Flood damages place a large financial burden on the government as a result of requests for compensation. Previously, insurance policies excluded coverage for flood damages, and the government was responsible for all claims. In 2000, a special committee convened by the Netherlands' government provided recommendations on flood insurance policy (Kok et al. 2002). The committee recommended that the government work with insurance companies to designate flooding as a result of high rains (and no failure of flood defense systems) as part of property insurance. This reduced the governments' exposure to flood damage claims (Kok et al. 2002).

Public-private enterprises can help finance flood system improvements. Two recent partnerships include gravel and sand production and urban planning. The Grensmaas project combined private gravel and sand extraction with floodplain lowering (van Stokkom et al. 2005). Private enterprises have also presented plans for floating villages, which allow for river dikes to be moved further inland and maximize the public's willingness to pay for riverfront property. Although these partnerships have potential, so far implementation has been difficult and inefficient (van Stokkom et al. 2005).

Recent Developments in Dutch Flood Management: Room for the Rivers

The Dutch are increasingly incorporating resilience strategies in their flood management policies. This is increasingly important as the economic value protected by the flood management system increases faster than dike heightening can occur. The economic value protected has increased nationally by a factor of six in the past 40 years, and more in many local areas. Two strategies are receiving the most attention as potential resilience methods to minimize economic consequences of flooding: storing flood waters and increasing maximum flow capacity of channels (Vis et al. 2003, Hooijer et al. 2004, Silva et al. 2004). In the Netherlands, these two strategies are part of creating "room for rivers," an initiative led by the Dutch government to provide better flood protection and use spatial planning for long-term development (Woorden 2006). The plan includes implementation of resilience measures in the four ways, by dike or levee relocation (setbacks), flood bypasses or "green rivers", lowering floodplains between the river and the levees, and developing flood detention areas (Hooijer et al. 2004).

The Dutch are currently building a flood bypass along the Ijssel branch of the Rhine to protect the towns of Veessem and Hoenwaard from flood waters. This channel is being built in a mostly agricultural area (Woorden 2006). As part of the same government measure to ensure flood protection objectives are met by 2015, the Dutch are also moving dikes along the Meuse between Geertruidenberg and Waalwik. By moving the dikes further from the river, the area known as the Overdiep Polder will be expanded and water levels in the area will drop up to 30 cm (Woorden 2006). Although both measures reduce developable land, the goal is to maintain agricultural use while protecting more populated areas.

Detention of floods in compartments requires designating areas for temporary water storage and subdividing existing dike rings. The compartmentalized sections will have different flood probabilities resulting from a pre-determined order for rerouting flood waters to the compartments (Vis et al. 2003, Silva et al. 2004). Upstream compartments are filled first to reduce the flood peak's height and duration further downstream. Typically, the compartments designated to receive flood waters first should be designated as natural or agricultural lands to minimize economic damage (Vis et al. 2003). These detention compartments also can be managed to help recharge groundwater supplies, reduce river bed erosion, and improve biodiversity (van Stokkom and Smits 2002).

Silva et al. (2004) evaluated the potential for compartmental detention for Rhine flood waters. Because upstream storage is most desired, the Netherlands would have to focus on areas near the German border. To reduce flood water flow from an "average" flood hyetograph by 1000 m^3/s, 150 million m^3 of storage is required. This is equivalent to 3000 hectares (30 km^2) flooded to 5 meters (Silva et al. 2004). An increase of 1000 m^3/s from 15,000 m^3/s (current maximum flow capacity) to 16,000 m^3/s results in the probability of the detention area being used in a given year being approximately 1 in 500 (Silva et al. 2004). Such a low probability may lead to people forgetting the purpose of the detention area and begin development in ways that diminish its effectiveness at lessening flood damages.

Green rivers or flood bypasses are one method to increase the maximum flow capacity of part of a channel. Green rivers are designated areas where water flows only during flood periods and may be used for agriculture or ecological habitat at other times (Vis et al. 2003, Silva et al. 2004). These are similar to the flood bypasses in California's Central Valley, but with greater environmental emphasis. In the Netherlands, green rivers typically flood during the off-season for agriculture, providing an economic benefit.

Two final strategies for creating room for the rivers are relocating existing levees or lowering flood plain levels. These strategies require having enough undeveloped or minimally developed land available to adequately set back the levee or lower the floodplain. In the Netherlands, this is often difficult because flow capacity restrictions, or bottlenecks, most often in urban areas with little undeveloped land (Hooijer et al. 2004, Silva et al. 2004).

Implications for California Flood Mitigation

Flood Control Structures

The history of flood control structures in California is similar to that of the Netherlands, although on a different time scale. Initially, flood-control efforts were undertaken by local interests -- typically nineteenth century settlers building their own rudimentary defense system with a lack of knowledge about flood periods and water heights (Harding 1960, Kelley 1989). In the twentieth century, local, state and federal agencies began to cooperate to build flood control systems. One of the earliest cooperative governmental projects was in 1916 to construct flood by-passes that are still in operation today (Harding 1960).

The U.S. Army Corps of Engineers, in cooperation with state and local agencies, constructed 1600 miles of federal levees in the Sacramento and San Joaquin River basins, also known as the Central Valley. Following construction, the federal government turned over maintenance of the levee system to the state. An additional 700 miles of non-federal levees have been constructed by landowners and local reclamation districts. These levees mostly protect agricultural land with the exception of Sacramento and its growing suburbs. Today, California's levees are regulated by the state Reclamation Board. Approximately 1300 miles of floodways have been designated by the Reclamation Board for flood discharge. The state, along with local reclamation and water districts, operates and maintains the extensive system of dams, levees, weirs, channels and bypasses along the Sacramento and San Joaquin Rivers.

Much like the Netherlands, the flod protection system is under increased pressure as development and demand for housing and land increase. Today, these levees protect over $47 billion in Central Valley infrastructure (www.water.ca.gov/levees). One example of this increased pressure is the Natomas neighborhood of Sacramento. The 53,000 acre Natomas area and its 70,000 residents contribute upwards of $4 billion/year to the local economy each year (Lamb 2008). A recent reclassification of the 43 miles of levees that protect Natomas from flooding on all four sides has resulted in a construction permit moratorium and a tripling in required flood insurance (Lamb 2008). According to FEMA and the Army Corps of Engineers, the levee system would not meet the safety standards during a storm that has a 3 percent chance of occurring, which equals a 60 percent chance of occurring during a 30-year mortgage (Lamb 2008). The construction moratorium has halted growth in an area that accounts for 47 percent of new development in the greater Sacramento area. The Sacramento Area Flood Control Agency has pushed the levee improvements in Natomas to its top priority, and has a plan to allow the area to meet FEMA standards (described below) by 2010. This work is funded in part with $49 million from a state bond measure passed in 2006.

Reliability-based Design

The Flood Insurance Administration of the Federal Emergency Management Agency (FEMA) uses the 100-year flood as a "base flood" to determine floodplains and flood insurance requirements and premiums under the National Flood Insurance Program (Federal Emergency Management Agency 2008). These floodplain maps often lead citizens to believe that they are more protected and "safer" from flood damage than they actually are (Moser 1997, White 1945).

The state of California has used a standard project flood to evaluate flood protection systems. This standard project flood is meteorologically based and is a derived discharge from a storm with a set return period. The Central Valley level of protection standard is a rain event with a return period ranging from a 200 to 500 years (Galloway et al. 2007).

Much like engineers in the Netherlands, the USACE historically used a design flood plus a freeboard when constructing flood defense systems (typically called flood reduction measures by the Corps). Often the design flood was the 100-year flood, or 1 percent exceedance flood (Commission on Geosciences, Environment and Resources 2000) in accordance with the FEMA National Flood Insurance Program standards. The freeboard is included to account for uncertainties in the discharge, stage, and damage of a flood (Moser 1997). Recently the USACE has shifted to a risk-based approach, discussed next.

Risk-based Design

When the U.S. Congress passed the Flood Control Act of 1936, it required consideration of the consequences following flood control structure failure. However, it was not until after van Dantzig's work that the economic costs were explicitly considered. H.D. Pritchett in 1964 provided an early U.S. risk-based design for the hydraulic design of highway drainage culverts (Tung 2005).

Although early USACE flood design was reliability-based, in the 1990's, there was a push within the USACE to transition to a risk-based analysis (Figure 3). First, the discharge associated with a standard set of exceedance probabilities (p = 0.5, 0.2, 0.1, 0.04, 0.02, 0.01, 0.004, and 0.002) (upper right-hand of figure) is determined. Then the discharge-stage relationship is determined (upper left-hand of figure). The stage (H), is then related to a damage function (lower left-hand of figure), which is then related back to the exceedance probabilities originally input in the first step (lower right-hand of figure) (Commission on Geosciences, Environment and Resources 2000).

Following this analysis, the USACE makes evaluations based on national economic development. This decision rule requires the USACE to invest funds in projects that have a risk-reward tradeoff at a national level (Yoe 1993). This may mean that local interests would increase the level of protection based on the economic trade-offs, but at the federal level, the additional spending can achieve greater reward elsewhere (Yoe 1993). This does not exclude local governments from providing additional funding to reach the increased level of protection (Moser 1997). Some academics have applied related risk-based analysis to evaluating flood protection for islands in the Sacrament-San Joaquin Delta (Suddeth et al. 2008).

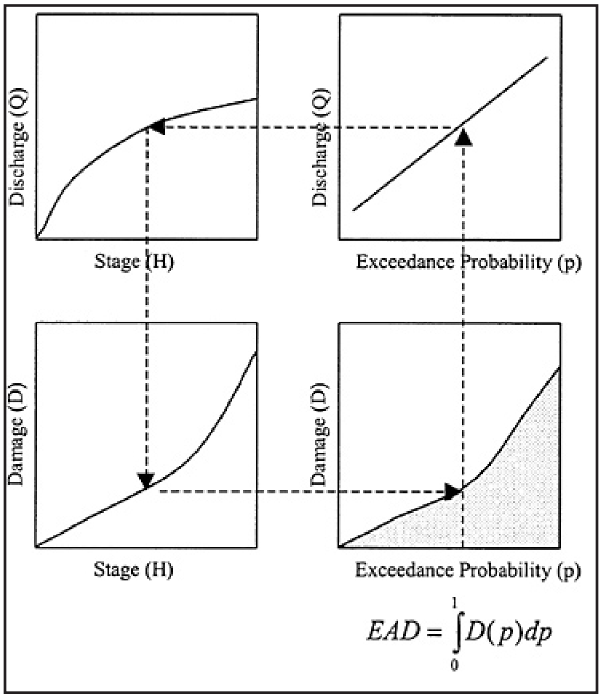

Figure 3. USACE Risk-Based Analysis Schematic (Moser 1997)

Financing Flood Protection

Federal policies and responsibilities for flood control were first established in 1917 with the Flood Control Act. Although this act was mostly related to flood control along the Mississippi River, a Sacramento River flood-control project was included with federal obligations limited to navigation (Harding 1960).

Over time, the role of the federal government in flood-control was broadened. The 1936 Flood Control Act included the construction of dam and reservoir projects as a federal responsibility. Gradually, by the mid-twentieth century, the federal government had assumed responsibility for most of the costs of flood control construction with the exception of payments for local right-of-way, which states typically cover. Local costs for flood control were limited to some maintenance (Harding 1960).

Today, the state of California has assumed much of the financial burden for levee maintenance. In 2006, voters passed a $4.09 billion bond measure (Proposition 1E) for levee repairs and flood control system maintenance, with $3 billion allocated for levee improvements. Repayment of these bonds will cost the state government approximately $8 billion over 30 years.

Local reclamation district funding ranges from slightly more than $50,000 in Yuba City to more than $2.1 million in Natomas (suttertaxpayers.com). In Sutter County, homeowners pay approximately $25 per year in Reclamation District taxes. In Yuba City, this funding goes to mostly administrative costs, and levee inspections and repairs are done by volunteers.

The California State Water Code Section 8400, Flood Hazard, requires that relevant local governments participate in the National Flood Insurance Program, as supplemented with state provisions (May 1993). To receive federal disaster aid following flooding, FEMA requires participation in the Program (FEMA 2002). In turn, the California state requirement ensures that local areas will receive aid in the event of a flood.

Insurance covers much of flood losses in the U.S. For the period of 1985-1999, although North America sustained only one-third of economic losses due to natural disasters, it accounted for over two-thirds of the insurance-protected losses sustained worldwide (Linnerooth-Bayer and Amendola 2003). The U.S. has approximately 4.3 million flood insurance policies covering over $606 billion in property (FEMA 2002).

The National Flood Insurance Program has been one of the most effective measures at reducing economic loss during a flood because of the safety standards required of insured properties. FEMA estimates that $1 billion in flood damages are avoided each year for new construction meeting its regulations, and that the new structures suffer 80 percent less loss during a flood event (FEMA 2002).

However, there is a need for more consistent maintenance of the levee systems. The Army Corps of Engineers estimates the cost of levee improvements in the Natomas area at more than $1 million per levee mile. With 43 miles of levees in this area, even one of the largest reclamation districts' operating budgets is insufficient to meet minimum standards. Emergency bond measures and disaster relief funding become overly expensive as interest rates and payback periods double the cost of the levee improvements, as in the case of Proposition 1E.

California shares a flood protection funding crunch with the Netherlands. However, two financial resources used in the Netherlands may aid California. Public- private partnerships might aid areas of high development like Natomas. By requiring land developers to provide flood protection funding as part of the permitting process, levee improvements can be made. Although it places a premium on the real estate being developed (theoretically equal to the cost of the flood protection provided), the results can be positive. One example of a developer funded levee project is the 1.3 mile set-back levee along Bear River near Plumas Lake (Dickey 2007). A $29,345 fee was assessed for each home in the new development. Initially, limited development was authorized before the levee was completed to help raise the nearly $70 million required to build the levee. Builders were also required to fund each homeowner's first year of flood insurance to ensure they were aware of the flood risk in the Plumas Lake area.

Making Room for the River: Bear River and Yolo Bypass

The levee along Bear River near the Plumas Lake developments provides a Californian example of the Dutch technique of "making room for the river." The set-back levee has provided an additional 600 acres of habitat that will ease pressure on the river during floods (Dickey 2007).

The Yolo Bypass is also an example of making room for rivers; it is an example of a "green river." At 59,000 acres, the Yolo Bypass is the largest bypass in the Sacramento Valley, and during flood events can discharge to the estuary much more than the main channel of the Sacramento River (up to 14 to 15 thousand m^3/s) (Schemel et al. 2002). During the winter and spring, the Yolo bypass is flooded, offering shallow-water habitat to aquatic species. Then, during the late spring and summer, when the bypass is not flooded, the land is used for irrigated agriculture (Schemel et al. 2002). Bypass construction started in 1917 after federal funding was approved to help the state government coordinate reclamation, navigation, and flood control projects (Kelley 1989). Since its completion, the bypass has been the main floodway for the Sacramento Valley (Jones and Stokes 2001).

Summary and Conclusions

Floods are a problem of too much and not enough- too much water and not enough money or space. The Dutch have centuries of experience trying to maintain the balance between flood damage and control. Advances in risk-analysis of flood defense systems and the accuracy of the valuations used in making economic decisions have been applied by the USACE in the last decade. The National Economic Development decision-rule directs federal funding to projects with the greatest economic value to the U.S. Reliability-based standards (using a predetermined failure probability) fails to account for the value of the land and lives being protected. Applying the same level of protection to agricultural land as to heavily populated cities is economically inefficient. The inadequacies of reliability-based design have been exposed, but continue to be used for flood insurance and, thus, many design purposes in California.

Public-private partnerships, which are in the early stages in both the Netherlands and California, have shown more potential in California. The Plumas Lake example shows that when developers assume some of the risk and cost of flood management, there can be economic benefits to the local government. The local government was able to save on the cost of the levee construction and establish a tax base for future levee maintenance.

Flood insurance in the United States and California goes far beyond insurance in the Netherlands. In the Netherlands, much of the burden for flood damage is on the government, including all damage caused by a failure of the flood defense systems to adequately protect homes. The increase in national and local economic values occurs faster than the government can develop adequate flood protection infrastructure.

In the U.S., the National Flood Insurance Program has provided an economic stimulus for more responsible construction and development that local and state governments would otherwise ignore. Additional state and federal funding from bond measures aids local governments in maintaining adequate flood protection and lowering insurance premiums for residents. The Natomas area provided an example of local and state failure to upgrade agricultural levees were adequately protect new urban development.

Finally, "making room for the river," has been used for decades in the example of the Yolo bypass and then was revisited to improve Plumas Lake flood protection. The bypass solution also incorporates the environmental value that Californians place on wildlife habitat and open, green space. However, it will not work in all locations. Much like congested areas of the Netherlands, making room for the river will not work in California's populous areas or areas where development along the river already exists (i.e. Natomas in the Sacramento area).

This review of flood protection methods in the Netherlands and California has reestablished the importance of land-use planning and risk-based analysis. It is expensive to build haphazardly in floodplains (Mount 1995). The costs of flood protection (a levee the size of the 90 m x 32 km Afsluitdijk) and the loss following a flood disaster (especially one that does not meet FEMA and National Flood Insurance Program criteria for federal disaster relief) both have the potential to drain the economic resources of the state of California.

Acknowledgements

We thank Professors Timothy Ginn and Levent Kavvas for comments on earlier draft.

Author Bios and Contact Information

Dana Woodall is an officer with the US Coast Guard in Seattle, Washington. She completed her joint MS in Civil and Environmental Engineering and MBA at the University of California - Davis. She can be reached at Dana.L.Woodall@uscg.mil.

Jay R. Lund is the Ray B. Krone Professor of Environmental Engineering at the University of California - Davis. He can be reached at jrlund@ucdavis.edu.

References

Barras, J., S. Beville, D. Britsch,, S. Hartley, S. Hawes, J. Johnston, P. Kemp, Q. Kinler, A. Martucci, J. Porthouse, D. Reed, K. Roy, S. Sapkota, and J. Suhayda. 2003. *Historical and Projected Coastal Louisiana Land Changes: 1978-2050*. U.S. Geological Survey Open File Report 03-334.

Al-Futaisi, A. and J. R. Stedinger. 1999. Hydrologic and economic uncertainties and flood-risk project design. *J. of Water Res. Plng. and Mngmt,* Vol. 125(6), pp. 314-324.

Apel, H., A. H. Thieken, B. Merz, and G. Bloschl. 2004. Flood risk assessment and associated uncertainty. *Natural Hazards and Earth System Sciences*, Vol. 4, pp. 295-308.

Baan, P. J. A. and F. Klijn. 2004. Flood risk perception and implications for flood risk management in the Netherlands. *Intl. J. River Basin Management,* Vol. 2(2), pp. 113-122.

Beenakker, C. 2008. The Zuidersee project. Institut-Lorentz website: http://www.lorentz.leidenuniv.nl/history/zuiderzee/zuiderzee.html.

Burn, D. H. 1999. Perceptions of flood risk: A case study of the Red River flood of 1997. *Water Resources Research*, vol. 35.(11), pp. 3451-3458.

California State Department of Water Resources (DWR) website. Floodplain management page: http://www.fpm.water.ca.gov/

Cameron, D. 2007. Flow, frequency, and uncertainty estimation for an extreme historical flood event in the Highlands of Scotland, UK. *Hydrol. Process.*, Vol. 21, pp. 1460-1470.

Commission on Geosciences, Environment and Resources. 2000. Risk Analysis and Uncertainty in Flood Damage Reduction Studies. National Academy Press: Washington, D.C.

Dickey, J. , 2007. Feds Praise Yuba Levee. *Marysville Appeal-Democrat [on-line].* http://www.appeal-demcrat.com/common/printer/view.php?db=marysville&id=49163 , May 30, 2007.

Disco, C. and J. van den Ende. 2003. Strong, invincible arguments? Tidal models as management instruments in Twentieth-Century Dutch Coastal Engineering. *Technology and Culture,*Vol. 44 (3), pp. 502-535.

Ermolieva, T., Y. Ermoliev, G. Fischer, and I. Galambos. 2003. The role of financial instruments in integrated catastrophic flood management. *Multinational Finance Journal,* Vol. 7 (3 & 4), pp. 207-230.

Feather, P. D. Hellerstien, and L. Hansen. 2000. *Economic Valuation of Environmental Benefits and the Targeting of Conservation Programs: The Case of the CRP.* USDA, Economic Research Service.

Federal Emergency Management Agency. 2002. *National Flood Insurance Program: Program Description.* FEMA document, https://www.fema.gov/library/viewRecord.do?id=1480, dated August 01, 2002.

Federal Emergency Management Agency (FEMA) website. Flood page: http://www.fema.gov/hazard/lood/index.shtm

Galloway, G. E., J. J. Boland, R. J. Burby, C. B. Groves, S. L. Longville, L. E. Link, J. F. Mount, J. Opperman, R. B. Seed, G. L. Sills, J. J. Smyth, R. Stork, and E. A. Thomas [Independent Review Panel]. 2007. A California Challenge- Flooding in the Central Valley. California State Department of Water Resources.

Greenwich Mean Time website. Map of Netherlands page:http://wwp.greenwichmeantime.com/time-zone/europe/european-union/the- netherlands/map.htm.

Haeuber, R. A. and W. K. Michener. 1998. Policy Implications of Recent Natural and Managed Floods. *BioScience,* Vol. 48 (9), pp. 765-772.

Hall, J. W., I. C. Meadowcroft, P. B.Sayers, and M. E. Bramley. 2003. Integrated Flood Risk Management in England and Wales. *Natural Hazards Review,* Vol. 4 (3), pp. 126-135.

Harding, S. T. 1960. Water in California. N-P Publications: Palo Alto, CA.

Haveman, R. H. 1965. Water Resource Investment and the Public Interest: An Analysis of Federal Expenditures in Ten Southern States. Vanderbilt Univ. Press: Nashville, TN.

Hoes, O. and W. Schuurmans. 2006. Flood standards or risk analyses for polder management in the Netherlands. *Irrig. And Drain.,* Vol. 55, pp. 113-119.

Hooijer, A., F. Klijn, G. Bas M. Pedroli, and AD G. Van Os. 2004. Towards sustainable flood risk manangement in the Rhine and Meuse River Basins: Synopsis of the Findings of IRMA-SPONGE. *River Res. Applic.* Vol. 20, pp. 343-357.

Huisman, P. 2002. How the Netherlands finance public water management. *European Water Management Online.*http://www.ewpca.de/journal/2002_03l.pdf

James, L. D. 1967. Economic analysis of alternate flood control measures. *Water Resources research,* Vol. 3 (2), pp. 333-343.

James, L. D. and R. R. Lee. 1971. Flood Control. Economics of Water Resources Planning. McGraw-Hill: New York.

Jones and Stokes. 2001. A Framework for the Future: Yolo Bypass Management Strategy. J & S 99079. Prepared for Yolo Basin Foundation , Davis, CA.

Jonkman, S.N., M. Brinkhuis-Jak, and M. Kok. 2004. Cost benefit analysis and flood damage mitigation in the Netherlands. *HERON*, Vol. 49 (1).

Kaijser, A. 2002. System building from below: Institutional change in Dutch water control systems. *Technology and Culture,* Vol. 43.

Kelley, R. 1989. Battling the Inland Sea: Floods, Public Policy and the Sacramento River. Univ. of Cal. Press: Berkeley, CA.

Kok, M., J. K. Vrijling and P. H. A. J. M. Van Gelder, and M. P. Vogelsang. 2002. Risk of flooding and insurance in The Netherlands. *Flood Defence.* Science Press: New York.

Kortenhaus, A. and H. Oumeraci. 2001. Risk-based Design of Coastal Flood Defences: Concept, Problems and Challenges. *Planung und Katastrophenvorsorge,* pp. 93-102. Zweites Forum Katatrophenvorsorge 2001.

Kuiper, E. 1971. Water Resources Project Economics. Butterworths: London.

Lamb, C. 2008. Natomas flood-risk report could halt construction. *Sacramento Business Journal [on-line].* http://sacramento.bizjournals.com/sacramento/stories/2008/01/14/daily23.html. January 15, 2008.

Larson, D. J. 1996. Historical Water-Use Priorities and Public Policies. *Sierra Nevada Ecosystem Project: Final Report to Congress,* Vol. 2, pp. 163-168.

Lenders, H. J. R, M. A. J. Huijbregts, B. G. W. Aarts, and C. A. M. van Turnhout. 1999. Assessing the degree of preservation of landscape, natural and cultural-historical values in river dike reinforcement planning in the Netherlands. *Regul. Rivers: Res. Mgmt.,* Vol. 15, pp. 325-337.

Linnerooth-Bayer, J. and A. Amendola. 2003. Introduction to Special Issue on Flood Risks in Europe. *Risk Analysis,* Vol. 23 (3), pp. 537-543.

Lintsen, H. 2002. Two centuries of central water management in the Netherlands. *Society for the History of Technology. Technology and Culture,* Vol. 43 (3), pp. 549-568.

Maps of the World website. California Rivers Page: http://www.mapsofworld.com/usa/states/california/california-river-map.html.

May, P. J. 1993. Mandate design and implementation: Enhancing implementation efforts and shaping regulatory styles. *J. of Pol. Anal and Mngmt,* Vol. 12 (4), pp. 634-664.

McDaniels, T. L., R. S. Gregory, and D. Fields. 1999. Democratizing risk management: Successful public involvement in local water management decisions. *Risk Analysis,* Vol. 19 (3), pp. 497-510.

Moser, D. A. 1997. The Use of Risk Analysis by the U.S. Army Corps of Engineers. *USACE Risk Analysis for Water Resources Investments Research Program.* Institute of Water Resources, Army Corps of Engineers.

Mount, J.F. 1995. *California Rivers and Streams: The Conflict Between Fluvial Processes and Land Use.* University of California Press, Berkeley, CA.

Nathwani, J. S., N. C. Lind, and M. D. Pandey. 1997. Affordable safety by choice: the life quality method. Institute for risk research, University of Waterloo, Canada.

Netherlands Environmental Assessment Agency and National Institute for Public Health and the Environment. 2004. *Dutch dikes and risk hikes: A thematic policy evaluation of risks of flooding in the Netherlands.* Extended summary.

Olsthoorn, A. A. and R. S. J. Tol. 2001. Floods, flood management and climate change in The Netherlands. Institute for Environmental Studies, Vrije Univ.: Amsterdam.

Reducing Flood Losses: Is the 1% Chance Flood Standard Sufficient? Report of the 2004 Assembly of the Gilbert F. White National Flood Policy Forum, Washington, D.C. September 21-22, 2004.

Sayers, P. B., J. W. Hall, and I. C. Meadowcroft. 2002. Towards risk-based flood hazard management in the UK. *Proceedings of ICE, May 2002,* pp. 36-42.

Sayler, S. 2006. Flood protection, Netherlands. *Canary Project.* www.canary-project.org/photos_netherlands.php.

Schemel, L. E., M.H. Cox, S. W. Hager, and T. R. Sommer. 2002. Hydrology and Chemistry of Floodwaters in the Yolo Bypass, Sacramento River System, California, During 2000. U.S. Geological Survey, Water Resources Investigations Report 02-4202.

Schmandt, J., E.T. Smerdon, and J. Clarkson. 1988. State Water Policies: A Study of Six States. Praeger: New York.

Silva, W., J. P. M. Dijkman, and D. P. Loucks. 2004.

Flood management options for The Netherlands. *Intl. J. River Basin Management,* Vol. 2 (2), pp. 101-112.

Singh, V. P. and W. G. Strupczewski. 2002. On the status of flood frequency analysis. *Hydrol. Process.,* Vol. 16, pp. 3737-3740.

Staatsblad. 21 December 1995. Flood Defence Act.

Suddeth, R., J. Mount, and J. Lund, "Levee Decisions and Sustainability for the Sacramento-San Joaquin Delta," Appendix B to *Comparing Futures for the Sacramento-San Joaquin Delta*, Public Policy Institute of California, San Francisco, CA, August 2008.

Sutter County Taxpayers Association (SCTA) website. 2008. *Funding of Levee and Reclamation Districts.* http://www.suttertaxpayers.com/funding.html.

Tol, R. S. J. and A. Langen. 2000. A concise history of Dutch river floods. *Climatic Change,* Vol. 46, pp. 357-369.

Tol, R.S.J., N. van der Grijp, A.A. Olsthoorn, and P.E. van der Werff. 2003. Adapting to Climate: A Case Study on Riverine Flood Risks in the Netherlands. *Risk Analysis,* Vol. 23 (3), pp. 575-583.

Tung, Y. 2005. Flood Defense Systems Design by Risk-based Approaches. *Water Intl.*, Vol. 30 (1), pp. 50-57.

U.S. Army Corps of Engineers. Press-Release 2008. *Corps reveals findings from Natomas levee analysis.* http://www.spk.usace.army.mil/organizations/cespk-pao/news/Natomas%20levee%20analysis.html.

U.S. Water Resources Council. 1962. *Policies, Standards, and Procedures in the Evaluation and Review of Plans for the Use and Development of Water and Related Land Resources.* Senate Document 97 of Eighty-seventh Congress, second session.

Van Dantzig, D. 1956. Economic Decision Problems for Flood Prevention. *Econometrica,* Vol. 24 (3), pp. 276-287.

Van Noortwijk, J. M. 2004. Bayes estimates of flood quartiles using the generalised gamma distribution. *System and Bayesian Reliability,* pp. 351-374.

Van Steen, P. J. M. and P. H. Pellenbarg. 2004. Water management challenges in The Netherlands. *Tijdschrift voor Economische en Sociale Geografie,* Vvol. 95 (5), pp. 509-598.

Van Stokkom, H. T. C., A. J. M. Smits, and R. S. E. W. Leuven. 2005. Flood defense in The Netherlands: A New Era, A New Approach. *Water International,* Vol. 30 (1), pp. 76-7.

Van Stokkom, H. T. C. and A.J.M. Smits. 2002. Keynote Lecture: Flood Defense in The Netherlands: A New Era, A New Approach. Second International Symposium on Flood Defense, Beijing, China.

Vis, M, F. Klijn, K. M. De Bruijn, and M. van Buuren. 2003. Resilience strategies for flood risk management in the Netherlands. *Intl. J. River Basin Management,* Vol. 1 (1), pp. 33-40.

Voortman, H. G. 2003. Risk-based design of large-scale flood defence systems. Print Partners Ipskamp BP: the Netherlands.

Voortman, H. G., P. H. A. J. M van Gelder, and J. K. Vrijling. 2002. Risk-based Design of Large - scale Flood Defence Systems. *Proceedings: 28th International Conference on Coastal Engineering (ICCE),* pp. 2373-2385.

Vrijling, J. K. and P. H. A. J. M. van Gelder. 1997. Societal Risk and the Concept of Risk Aversion. *Advances in Safety and Reliability,* Vol 1. Lissabon. pp. 45-52.

Vrijling, J. K., P. H. A. J. M. van Gelder, and S. J. Ouwerkerk. 2005. Criteria for acceptable risk in the Netherlands. *Infrastructure Risk Management Processes: Natural, Accidental and Deliberate Hazards.*

Walker, W. E., A. Abrahamse, J. Bolten, J. P. Kahan, O. van de Riet, M. Kok, and M. Den Braber. 1994. A Policy analysis of Dutch River dike improvements: Trading safety, cost, and environmental impacts. *Operations Research,* Vol. 42 (5), pp. 823-836.

Werner, M. and Whitfield, D. 2007. On model integration in operational flood forecasting. *Hydol. Process.,* Vol. 21, pp. 1519-1521.

White, G.F. 1945. *Human Adjustment to Floods*. Department of Geography Research Paper no. 29. Chicago: The University of Chicago.

Woorden, M. A. 2006. Spatial Planning Key Decision 'Room for the River:' Investing in the safety and vitality of the Dutch river basin region. *Ministry of Transport, Public Works and Water Management.*

Yanmaz, A. M. 2000. Overtopping risk assessment in river diversion facility design. *Can. J. Civ. Eng.,* Vol. 27, pp: 319-326.

Yoe, C. 1993. National Economic Development Procedures Manual: National Economic Development Costs. Institute for Water Resources: US Army Corps of Engineers.

Yue, S., T. B. M. J. Ouarda, B. Bobee, P. Legendre, and P. Bruneau. 2002. Approach for describing statistical properties of flood hydrograph. *J. Hyd. Eng.* Vol. 7 (2), pp. 147-153.