NOAA Technical Memorandum OAR PSD – 315

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BENEFITS OF AN ADVANCED QUANTITATIVE PRECIPITATION INFORMATION SYSTEM: SAN FRANCISCO BAY AREA CASE STUDY

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ABSTRACT

A case study for the San Francisco Bay area provides the context for quantification of the benefits of an Advanced Quantitative Precipitation Information (AQPI) system. An AQPI would dovetail with the current NWS forecast operations to provide incrementally higher resolution monitoring of rainfall events and longer lead time forecasts. Decisions on investments to obtain an operational AQPI system require demonstration that the benefits exceed the costs. Estimation of benefits involves characterization of the spectrum of human and ecological activities in which Bay area residents participate, including avoidance of flood damages, maximizing water supplies, and enhancing ecological, recreational and transportation services. A reconnaissance-level regional resource accounting approach has been developed to quantify AQPI benefits. Taken by category about 60% of the benefits are for flood damage mitigation ($37M/yr) with water supply (14%, $9M/yr), recreation (10%, $6.3M/yr), and transportation (14%, $8M/yr) following. The largest portion of the transportation benefit is for shipping. For the total AQPI system costs, which includes federal and other regional expenditures, the total initial costs are $66M initial and $3.3M annual O&M; these compute to a present value cost of $90M. Compared to present value benefit of $460M this computes to a B/C ratio of 5.1. Sensitivity analysis identified a range of B/C up to 13.7 and down to 1.7. It is important to acknowledge that many of the benefits are dependent on appropriate and adequate response by the hazards and water resources management agencies and citizens.

1. INTRODUCTION

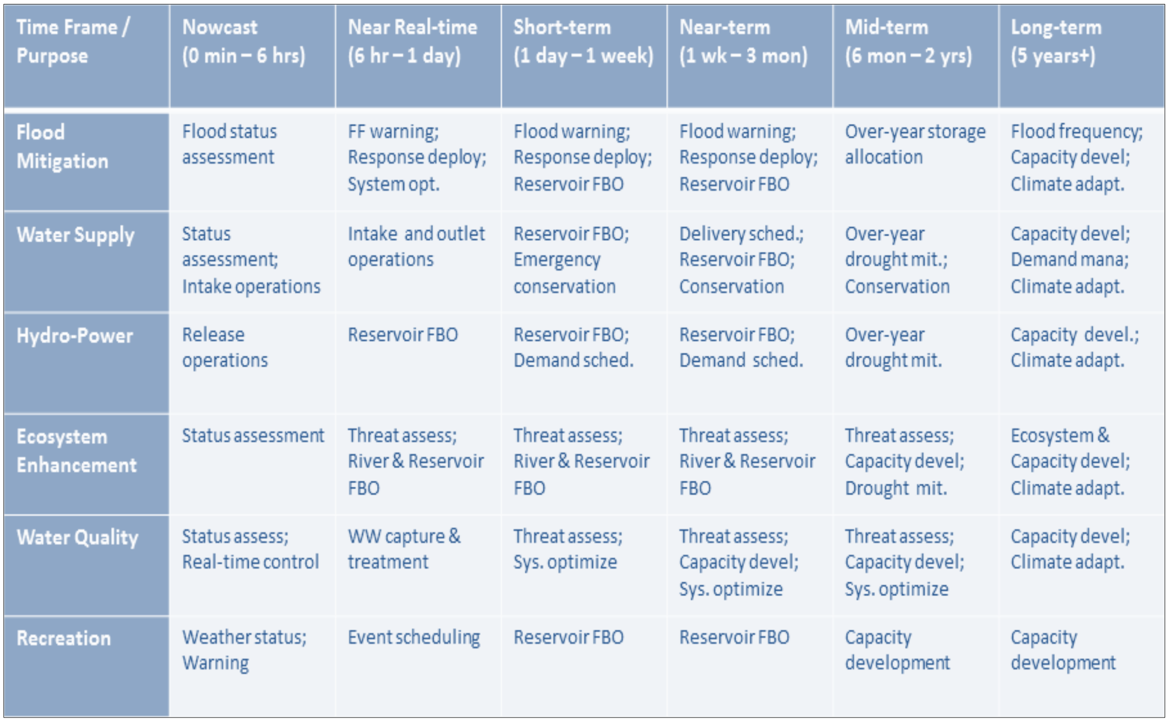
1.1. *Overview*

Advanced hydro-meteorological (i.e. hydromet) observations and forecasts can be critical to water resources management efforts in any location. The hydromet monitoring and forecasting programs of the Hydrometeorology Testbed (HMT) and National Weather Service (NWS) involve deployment of advanced sensor networks, assimilation of the data collected, application of various mathematical models of the atmosphere and watersheds, articulation of decision-relevant information, and dissemination of this information to users. These hydromet information services are conducted continuously 24 hours a day, 7 days per week, with focused operations during severe weather conditions. Procedures for accomplishing these activities are complex and there are on-going efforts to provide longer lead times at higher time and space resolutions with reduced uncertainty through advancement of monitoring technologies, data processing and communications. A recent strategic plan summarizes these efforts (NWS 2011, 2012).

1.2. *Hydromet Information Resources Management Actions and Time Frames*

Public safety and resource management responses for a spectrum of weather and climate forecast time frames are summarized in Table 1. The time frames range from real-time (nowcasting) updates on weather and river flow conditions, to short- and near-term seasonal forecasts, and ultimately to long-term climatic-type forecasts. Depending on the resource management purpose there are various actions which might be taken to maximize performance and/or to mitigate adverse impacts of severe weather and too much or too little water. Selected examples of resource management actions are summarized following.

Table 1 Hydromet Management Actions and Time Frames.



Time Frame / Purpose	Nowcast (0 min – 6 hrs)	Near Real-time (6 hr – 1 day)	Short-term (1 day – 1 week)	Near-term (1 wk – 3 mon)	Mid-term (6 mon – 2 yrs)	Long-term (5 years+)
Flood Mitigation	Flood status assessment	FF warning; Response deploy; System opt.	Flood warning; Response deploy; Reservoir FBO	Flood warning; Response deploy; Reservoir FBO	Over-year storage allocation	Flood frequency; Capacity devel; Climate adapt.
Water Supply	Status assessment; Intake operations	Intake and outlet operations	Reservoir FBO; Emergency conservation	Delivery sched.; Reservoir FBO; Conservation	Over-year drought mit.; Conservation	Capacity devel; Demand mana; Climate adapt.
Hydro-Power	Release operations	Reservoir FBO	Reservoir FBO; Demand sched.	Reservoir FBO; Demand sched.	Over-year drought mit.	Capacity devel.; Climate adapt.
Ecosystem Enhancement	Status assessment	Threat assess; River & Reservoir FBO	Threat assess; River & Reservoir FBO	Threat assess; River & Reservoir FBO	Threat assess; Capacity devel; Drought mit.	Ecosystem & Capacity devel; Climate adapt.
Water Quality	Status assess; Real-time control	WW capture & treatment	Threat assess; Sys. optimize	Threat assess; Capacity devel; Sys. optimize	Threat assess; Capacity devel; Sys. optimize	Capacity devel; Climate adapt.
Recreation	Weather status; Warning	Event scheduling	Reservoir FBO	Reservoir FBO	Capacity development	Capacity development

Resource management occurs over a wide range of time frames, from nowcasts to short-term to long-term. The shorter time frames are primarily directed to flood events; longer time frames involve water supply and drought management actions.

- Nowcasts on current conditions (0 to 6 hours) support reactive threat assessment on the extent and intensity of rainfall and flooding. Response agencies can deploy staff and resources to help prevent loss of lives and minimize property damages. Ground, sea and air traffic can be redirected and rescheduled.

- Near real-time (6 hours to 24 hours) allows for relocating furniture and moveable goods above flood levels. Also, decisions to capture of flood waters by reservoirs and to organize materials for flood fighting (e.g. sand bags) can be keyed to forecast flood events. Capture of urban storm water and combined sewer flows can also be optimized given rain forecasts in this time frame. Traffic for ground, seas and air transportation systems can be scheduled to maximize safety and avoid delays.
- Short-term forecasts (1 day to 1 week) of rainfall magnitude can enable forecast-based operations (FBO) which allow capture of flood waters to reduce downstream damages, and to store water to carry over into the dry season to sustain water supplies and reservoir releases for fisheries and water-related recreation.
- Near-term forecasts (1 week to 3 months) support reservoir FBO for larger river basins. Also, various adaptive actions can be taken to schedule supply deliveries and enact water conservation practices.
- Mid-term forecasts (6 months – 2 years) support adaptive actions for drought period water allocations and conservation practices. There may also be options for capacity development to mitigate high flows and droughts.
- Long-term (5 years and longer) actions include capacity development to adapt to climate change and increases in water supply demands for municipalities, irrigation and ecosystem enhancements. Records of precipitation amounts and extremes collected over long-term time frames support improved analyses of flood and water supply variability, and design of facilities and management approaches.

1.3. San Francisco Bay Area Case Study

San Francisco Bay Region

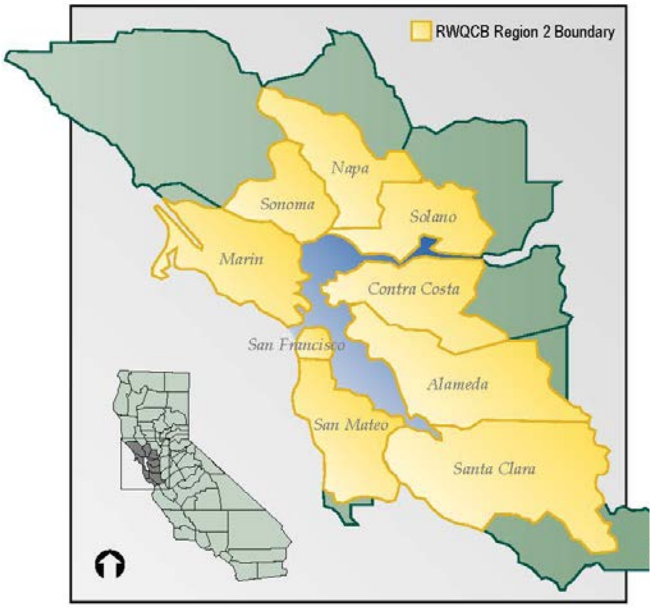


Figure 1 San Francisco Bay region is comprised of 9 counties (BAIRWMCC 2013).

The San Francisco Bay region includes all or portions of the nine counties which surround San Francisco Bay (known as the Bay Area), including Alameda, Contra Costa, San Francisco, San Mateo, Santa Clara, Marin, Napa, Solano and Sonoma counties (Figure 1). With a population of 7.2 million (in 2010), the San Francisco Bay metropolitan region is the second largest in California, and the fifth largest in the nation. The Region includes three major metropolitan cities and approximately 100 smaller cities and towns.

West Coast Weather - Atmospheric Rivers

According to a recent Department of Water Resources report California's Flood Future: Recommendations for Managing the State's Flood Risk (2013, http://www.water.ca.gov/sfmp/) - many parts of California, including the Bay area, are at risk of catastrophic flooding. In addition to public safety, existing infrastructure dedicated to transportation, water supply, and waste water can be negatively impacted by both long- and short-duration heavy rainfall events. Rain storms are highly variable in time and space and are not sufficiently resolvable using current rain gauge and weather radar information.

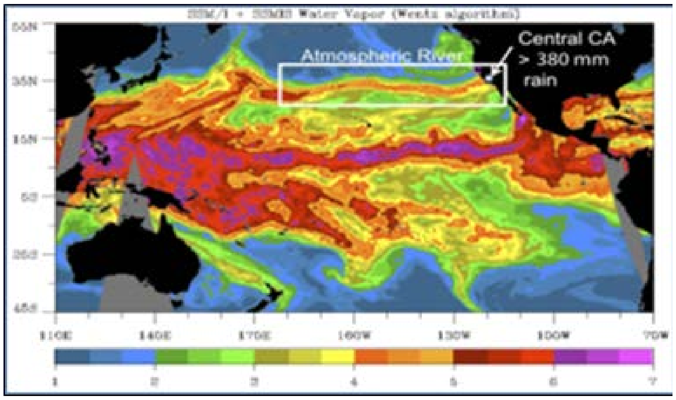


Figure 2 Atmospheric rivers are a primary source of floods and water supply along the California coast (Ralph et al 2006; http://www.esrl.noaa.gov/psd/atmrivers/).

Recent studies (e.g. Ralph, et al 2012) have documented the important role that ‘‘atmospheric rivers’’ (ARs) of concentrated near-surface water vapor above the Pacific Ocean play in the storms and floods in California, Oregon, and Washington. By delivering large masses of warm, moist air (sometimes directly from the Tropics, Fig 2), ARs establish conditions for the kinds of high snowlines and copious orographic rainfall that have caused the largest historical storms. In many California rivers, essentially all major historical floods have been associated with AR storms. Ralph et al. (2006) recently noted that every ‘‘declared’’ flood on the Russian River near Guerneville, California, during the past 10 years has been associated with the arrival of an AR.

Conversely, if AR events during the winter storm season do not occur, then there is threat of drought conditions and consequent impacts on water supply reliability. When an AR event occurs after a protracted dry spell, then it is called a “drought buster.” Dettinger et al. (2011) documented the major roles that ARs also play in California’s water supply, providing from 25% to 50% of an entire water-year’s precipitation in just a few events.

Even today, California’s aging water supply and flood protection infrastructure, including more than a thousand kilometers of levees, is challenged by punishing floods and increased standards for urban flood protection. Further, current climate-change projections for 21st Century California uniformly include warming by at least a couple of degrees, and, although great uncertainties remain about future changes in long-term average precipitation rates in California. It is generally expected that extreme precipitation episodes may become more extreme as the climate changes (Dettinger 2011).

Many Californians face unacceptable risks from flooding and droughts, both from where they live and work and from where they derive water supplies. In response to the risks and conflicts posed by flooding, the California Department of Water Resources Water Plan Updates strongly recommend that water supply management and land-use development be much more fully integrated with flood management in the State (DWR, 2005, 2009, 2013).

1.4. Advanced Quantitative Precipitation System

The Advanced Quantitative Precipitation Information (AQPI) System is a regional project activity being designed to be part of the Bay Area Integrated Regional Water Management Plan (BAIRWMP) program. The AQPI System can improve monitoring and prediction of precipitation throughout the San Francisco Bay region and

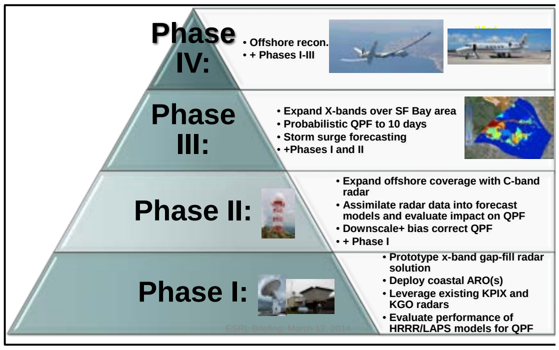


Figure 3. Phased approach for AQPI development and continuing operations will involve new gap-filling radars, high resolution numerical models, and system integration for real-time forecasting and warning operations.

enhance public safety through early warning and storm tracking. The AQPI System proposed for funding under BAIRWMP represents phases 3 and 4 of a 4-phase project that leverages more than a decade of NOAA–Hydrometeorology research, prototyping and implementing a statewide state-of-the-art network of precipitation observations (Figure 3).

Knowledge and expertise developed over the past 15 years in studying West Coast rainfall will be applied to improving both the temporal and spatial resolution of AQPI to better support the Bay area's requirements. The AQPI project being developed for the BAIRWMP would leverage over $30M in precipitation information systems by NOAA, State of California, and regional and local stakeholders. These investments come through collaboration in all phases of the AQPI implementation.

Phases 1 and 2 of the AQPI include a coastal Doppler weather radar which will point off shore to improve tracking of incoming low-level storms (1-6 hours lead time) and a number of lower cost gap-filling radars (up to 1 hour lead time), which provide high resolution coverage over populated and flood prone urban areas of the San Francisco Bay region. Phase 3 will augment this network with additional gap filling radars to provide coverage over the Bay Area and include high resolution forecasts out to 12 hours. The off-shore radar coverage will inform high resolution numerical models to improve forecast accuracy. In phase 4, offshore monitoring will reduce these errors providing better forecasts with several days lead time. Part of phase 3 is also improved runoff predictions. This will be valuable to wastewater and storm water managers, and will provide better inputs to urban hydrologic and coastal surge and wave models.

To address climate change and sea level rise with more extreme storms, Phase 3 will implement the Coastal Storm Modeling System (CoSMoS, Fig 4) to simultaneously forecast flooding along the coast and the San Francisco Bay margin due to tributary discharge and elevated Bay water levels from the increased run-off, along with waves, tides and storm surge associated with approaching storms.

The total initial AQPI project cost is $66M with $33M state and local share and $33M already invested and planned by the HMT, California DWR, City of San Francisco, Santa Clara, Sonoma County and others. The total cost covers implementation of Phases 2 and 3 in Fig 3.

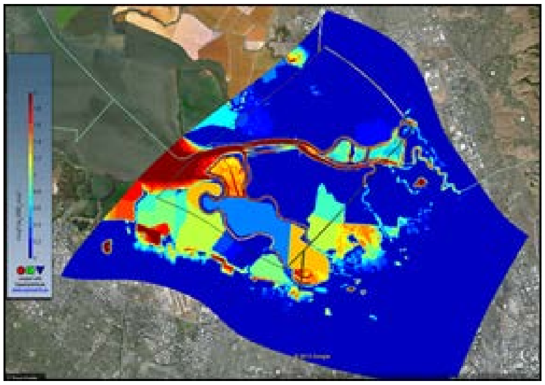


Figure 4. CoSMoS coastal storm surge and wave model will be applied.

The San Francisco regional AQPI system should be expected to provide benefits exceeding costs through, a) avoided flood damage costs from early warnings, b) forecast-based operations to maximize reservoir capture for water supply and fisheries flows, c) minimization of water quality impacts from combined and storm sewer systems, and d) enhancement of public safety and convenience for the various transportation modes (roads, trains, ports, and airports). These benefits will become increasingly important as damages associated with extreme weather events continue to increase.

This report addresses quantification of benefits of the AQPI system to provide a comparison to the system costs for implementation and operation. The intent is to provide a benefit-cost basis that would justify investment.

2. ECONOMICS OF HYDROMET INFORMATION

2.1. Hydromet Decision Making

Hydrometeorology (hydromet) information products made available by the NWS, HMT and other sources result in economic benefits because they are used by decision makers to make choices that affect economic well-being. Water and emergency managers often progress through multiple decision-making stages as information about a hazardous or influential weather event evolves. A generalized version of this event decision cycle is depicted in Figure 5. When no specific event requiring action is occurring or is on the immediate horizon, managers prepare and plan. If forecasts, environmental cues, or other information suggest increased potential for a hazardous weather event, emergency managers increase readiness, for example, by placing crews on call and more closely monitoring the situation. If information builds, suggesting the event is likely, imminent, or occurring, managers may initiate event-specific preparation, such as calling in personnel and positioning crews, and then activate emergency operations. Managers must also decide when the threat has passed so they can demobilize emergency operations (which can be as important as deciding when to activate). Throughout the cycle, they may consider "what if" scenarios, to aid planning and reduce the likelihood of surprises.

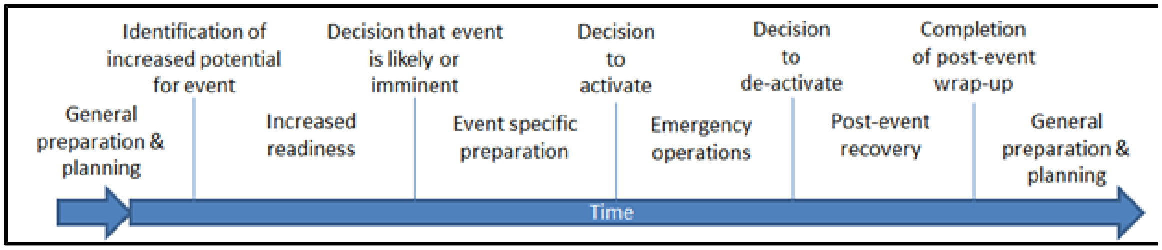


Figure 5 Major weather event decision cycle (after Morss and Ralph 2007)

A hydromet product, such as a real-time precipitation map, represents information about the environment. This information has value when it can be used by an individual or organization to make a better decision – that is, a decision that results in an outcome that is economically superior. A standard economic approach to valuing information requires (Kite-Powell 2005a):

- A description of the information being valued and of the state of knowledge about the phenomena or conditions it describes. Typically, information is useful because it reduces uncertainty about the present or future state of nature in a particular context – for example, the location of a particular flood threat, or the exact water level on a flood plain.
- A model of how this information is used to make decisions. Most decisions are made in the face of imperfect information, or uncertainty about how conditions will in fact develop and what the exact outcome will be. For example, NWS/HMT data may be used in decisions involving avoiding flood damages. Here, the critical information concerns water depth, or other information needed for the safe and efficient evacuation.
- A model of how these decisions affect physical outcomes. Modeling the difference in outcome with and without the product in question usually requires making assumptions about how the decision makers will respond to the lack of the product in question.
- A model of how physical outcomes can be translated into economic outcomes. The value of a product is the difference between the expected value of the outcome of decisions using that product, and the expected value of the outcome without the product.

2.2. Estimating Economic Benefits

Actions taken because of improved hydromet information yield benefits in four general categories; (these are described in terms for flood mitigation but the general categories apply for all water management domains).

- Direct tangible benefit. Tangible benefits are those to which monetary value can be assigned, and direct benefits are those that accrue to people and property who are ‘‘protected’’ by the system. These benefits can be in terms of <u>willingness to pay</u> (e.g. water sales) or <u>damages avoided</u>. An <u>alternative cost</u> concept may also be applied; this is the least cost of any viable way of obtaining the same physical benefit as the project.
- Indirect tangible benefit. These are economic benefits to those who are outside the impact area, such as less interruption of jobs located in a flood plain.
- Direct intangible benefit. Intangible benefits are those accrued that cannot be readily measured in monetary terms. Examples include protecting human safety and reduced stress.
- Indirect intangible benefit. These are non-economic benefits that accrue to those outside the impact area as a consequence of reduced stress. For example, the mental health of families and friends can suffer if word of a flood arrives and they cannot establish contact with floodplain occupants.

Several levels of confidence are identified for quantifying benefits of hydromet information:

- High Confidence. This level has reasonably good confidence involving direct evidence based on detailed data and field verifications.
- Moderate Confidence. This level requires more significant assumptions with less direct evidence. Results of detailed case studies may be transferred based on per person or other normalized factors.
- Low confidence or “Rules of Thumb”. These are highly generalized estimates based on indicators, for example, as a percent of the economic value generated by the activity, or some similar rubric. Low confidence may also be potential or speculative which could be realized with additional investment or a higher level of utilization by impacted people and businesses.
- Non-Quantified Benefits. These benefits cannot be quantified but are considered real. Examples include educational uses of the hydromet information and scientific research.

The level of confidence in the estimates is increased with the level of effort directed to specific details of impacted areas.

Methods for benefits estimation can involve a range of data collection and analysis procedures. These include market valuation, replacement or alternative cost, avoided cost, hedonic analysis, travel cost, contingent valuation and benefits transfer. These concepts are summarized in Appendices A and B. <u>The primary approaches applied herein include market valuation, avoided cost, and transfer of benefit values estimated in other studies.</u> An extensive literature review provided information on established methods for benefits estimation (Appendices A, B, C and D) and case study examples of methods’ application. Information from the literature can be used to identify and characterize data that can be transferred to area of interest. Interviews with water managers and other experts provide information on benefits that might be expected given availability of hydromet information having various lead times and levels of geographic detail. Post-event surveys of damages and observations can identify actions taken that reduced damages. Hydromet data reviews can provide details on severe events which can inform water managers on the character of the events, as well as forecasters who can use that data to improve their understanding of hydromet processes. Historical time series can be analyzed to identify storm precursors. Computer simulations of hydromet forcings (e.g. precipitation forecasts) and hydrologic responses can be applied. These studies involve assimilation of observed data and calibration of the atmospheric and hydrologic models, and can be applied to specific short-term events as well longer time series for facilities design (e.g. 100 years of daily precipitation).

This report emphasizes estimation of direct tangible "public" benefits using data that is readily available for jurisdictions across the region. It is not a detailed and formal economic analysis but more a reconnaissance-level tabulation of potential incremental benefits associated with the AQPI project. An extensive literature review provides the foundation for identifying public benefits, methods for estimation and indicators that can be transferred to the San Francisco Bay area. In general, the confidence levels for benefits estimations presented are in the Low to Moderate range.

2.3. Overview of Hydromet Forecast Benefits

A summary of the general benefits of hydromet forecasts includes the following:

- An average annual household value of $286 is placed on weather information (NWS 2011b).
- Households in at-risk hurricane states were willing to pay an additional $14 per year to receive more precise hurricane predictions 48 hours in advance (NWS 2011b).
- The benefit-to-cost ratio for hydromet information has been estimated to be 4.4 to 1 (Weiher and Lazo 2002).
- A ten percent reduction of flood damages can be expected using hydrologic forecasts for short-term events (NHWC 2002).
- A conservative estimate is made that NWS hydrologic forecast benefits are equal to 5 percent of the average annual flood damage prevented by the USACE reservoirs (Stallings 1997).
- The value of weather nowcast and forecast information is generally on the order of one percent of the value generated by the economic activity (Kite-Powell 2005).

Methods for estimating more specific benefits of precipitation and weather forecasts differ for the various water management purposes. The following sections provide detailed review of the values of hydromet forecasts for the various water management application sectors:

- Emergency Response for Flood Damage Mitigation
- Reservoir Storage for Flood Control and Water supply
- Ecosystems Services and Recreation
- Water Quality
- Transportation

2.4. Regional Benefits Accounting Approach

A regional multi-sector benefits accounting approach has been developed which involves application of readily available local data which can be related to more detailed studies at other locations as documented in the literature and various reports. Examples include population, visitor days, reservoir storage and river flows, and flood damages. Sections that follow present details on the benefits estimation approaches. Metrics used to quantify benefits for all of the sectors are tabulated at the end (Section 8).

3. EMERGENCY RESPONSE FOR FLOOD DAMAGE MITIGATION

There are three categories for deriving emergency response flood mitigation economic benefits: 1) nowcasts to near real-time (i.e. emergency forecasts; 0 to 24 hours), 2) short-term forecasts (1 day to 1 week), and 3) near-term forecasts (1 week to 3 months). Each of these can inform reservoir operation strategies.

3.1. Nowcasts to Near Real-Time (i.e. Emergency) Forecasts

Near real-time forecasts support warnings for flash floods, this could develop anytime up to approximately 6 hours from the time of heavy rainfall, and a flash flood watch may be issued up to 24 hours in advance. As might be expected, the primary objective of flash-flood warnings is to save lives since there is so little time to save personal belongings and property. However, some damages can still be avoided in the short term; for these situations the ten percent reduction guideline may be applied as a conservative estimate (NHWC 2002).

In many cases quantification of benefits is difficult, so more qualitative approaches are applied. For example, the use of near real-time hydromet forecast information for emergency management decision making was examined by Morss and Ralph (2007) for a flood (2–3 February 1998) on Pescadero Creek, CA which drains to the ocean south of San Francisco (see insert).

Pescadero Creek Flash Flood Case Study (Morss and Ralph 2007)

- Background: Observations confirmed NWS forecasters' concerns about heavy rainfall and flooding, and they issued a flash flood warning with an unusually long lead time. San Mateo emergency managers had sufficient confidence in the NWS forecast to begin assembling search and rescue crews and equipment and positioning them near the mouth of Pescadero Creek, in a location with access to the area at risk but out of harm's way. Several hours later, heavy rain caused record flooding on Pescadero Creek, triggered landslides, and washed out area roads and bridges. The crews positioned earlier rescued 129 people using inflatable boats; one resident died in the incident.
- Methods: The study methodology focused on the collection and analysis of qualitative (non-numerical) data using two methods: participant observations and semi-structured interviews. Supplemental data were gathered from documents (including NWS products such as Area Forecast Discussions), informal interviews and discussions, interactions with participants, and a site visit. Interviewees were selected based on their participation or interest or on recommendations from others [the snowball method; e.g., Weiss (1994)]. Participants included the NWS forecasters as well as emergency management staff.
- Benefits: Benefits were not estimated in monetary tems, but the Pescadero Creek case study determined that observations helped forecasters and emergency managers confirm their concerns about flooding, identify Pescadero Creek as a high-risk area with several hours lead time, and position lifesaving crews—all with sufficient lead time. The quality of the flash flood forecast, and the trust that users place with that forecast, play an important role in reducing the threats of loss of life and damages.

Many at-risk communities have implemented Automated Local Evaluation in Real Time (ALERT) flood-warning systems. One example of the value of an ALERT system was documented by Burnash (1984) who documented that following a flood in Ventura County, CA in February 1980, flood-control district officials estimated that $500,000 damages were prevented because of a recently installed $50,000 ALERT system. Estimates of the benefit-to-cost ratio for ALERT systems have varied from 50:1 to 10:1 (Stallings1997). The NWS estimates that the number of automated local flood warning systems nationally is approximately 400 indicating that benefits nationwide from these systems are in the millions of dollars annually.

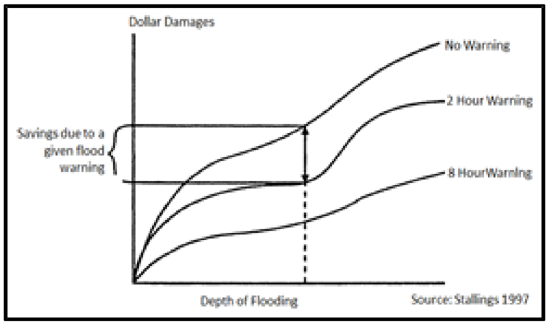


Figure 6 Illustration of value of lead time for flood damage reductions (from Stallings 1997).

3.2. Short-Term Forecasts

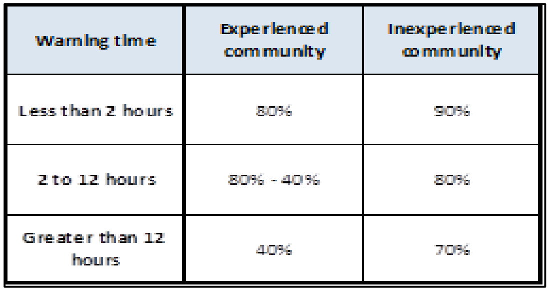
For floods with longer lead times (time between the issuance of the warning and the occurrence of the flood), the effectiveness of the warnings is measured in terms of saving both lives and property. Figure 6 illustrates the value of lead time for flood damage reductions. Saving property with less than 18 hours lead time is generally restricted to moving highly valued property, such as automobiles, equipment and major appliances, out of harm's way. When lead times are longer than 18 hours, floodplain residents can flood proof and flood fight (construct temporary levees, place sand bags, etc.).

Substantial research has been directed to the value of lead time. The mitigation time increase is a consequence of a reduction in the time required to collect data, to evaluate and identify the flood threat, to notify emergency personnel and the public, and to make decisions about the appropriate response.

Day (1966) developed and applied a technique to predict annual benefits resulting from the use of NWS hydrologic forecasts. The technique considers the probability of floods at a given depth and the dollar damage associated with the flooding depth. Day applied the technique for Meadville, PA and reported a total of 650 homes in the flooded area incurred damages totaling $1.43 million with no warning and $1.06 million with warning. These figures indicate a 27 percent reduction in damages due to NWS flood warnings. Similar studies (White, 1939; Houghton, 1962; Kates, 1965; and Bock and Hendrick, 1966) indicated a 10 to 40 percent reduction in flood damage due to hydrologic forecasts. A recent report for the California Department of Water Resources (CaDWR 2012) proposed the reduction factors shown in Table 2.

Day (1970) performed additional studies on the effectiveness of residential structures for reducing flood damage in the Susquehanna River basin resulting in the so-called “Day curve” (Fig 7) If the warning time is 0 h, the Day curve predicts that the flood warning system will provide no tangible benefit. If the warning time is 12 h, the Day curve predicts that the damage will decrease by 23%. For example, if the damage without warning is $1,000,000, and a flood warning system increases the mitigation time to 12 h, the damage reduction will be $230,000. Although the Day curve approach is acceptable for application anywhere today it has been criticized for 1) not being calibrated to specific floodplain conditions, and 2) being overly optimistic. Also, it presumes that property owners will actually receive warning messages and, if so, will act rationally and efficiently.

Table 2 Proposed ratios of actual vs potential damages (CaDWR 2012)



Warning time	Experienced community	Inexperienced community
Less than 2 hours	80%	90%
2 to 12 hours	80% - 40%	80%
Greater than 12 hours	40%	70%

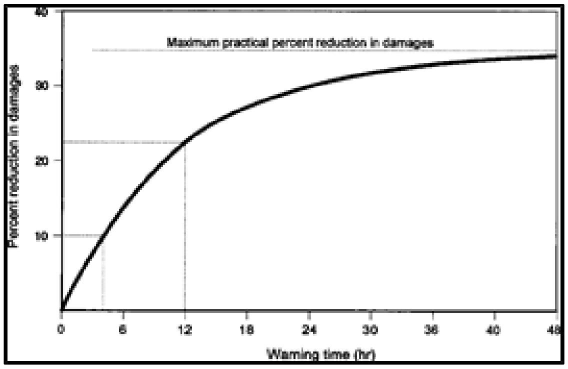


Figure 7 “Day’s curve” relates flood damage reductions to warning lead time.

The basic concept of the Day curve was extended by Carsell et al (2004) who developed a strategy for quantifying the benefit of increased mitigation time due to a flood warning system. Their approach is more data and analysis intensive as it involves computation of expected annual damages (EAD) using a modified depth-damage function for residential contents, appropriate for specific durations of mitigation time. It addresses specific floodplain properties and involves hydraulic modeling at the various flood levels to ascertain estimated actual damages.

A key aspect of the EAD concept is how the annual damages and reductions are estimated. For a single event the expected annualized damages are the damages multiplied by the probability of the event occurring in a given year. For example, the EAD of a 100-year flood event are the damages (D_{100}) x 0.01 or $D_{100}/100$. To account for the variability of damage due to floods of various magnitudes, the

‘‘Economic and environmental principles and guidelines for water and related land resources implementation studies’’ (U.S. Water Resources Council 1983) require that the EAD be computed as the product of the damages and flood probabilities integrated over the full range of events (see insert).

U.S. Water Resources Council (1983) stipulates use of expected annual damage (EAD), which is computed as

$$E[X] = \int_{-\infty}^{\infty} x f_x(x)\,dx$$

in which x = random value of annual damage that occurs with probability $f_x(x)$.

Although the EAD approach is data and analysis intensive, it is notable that the data do exist. For example, the DWR recorded (2009; 2013) that in California in 2000, almost 5 percent of California’s households were living in what is known as the “100-year” floodplain—an area susceptible to more frequent floods, where land use is regulated by federal flood policy and where federal flood insurance is required . Another 12.5 percent of households lived in the “500-year” floodplain, an area susceptible to larger, less frequent floods that have a 0.2 percent or more chance of occurring in any given year.

The Carsell et al. study (2004) also addressed concerns with the efficiency of the warning dissemination and respondent reactions. The following model was proposed to measure efficiency of flood warning:

- Efficiency = F_{rw} x F_w x F_c
    - F_{rw} = fraction of the public that receives a warning;
    - F_w = fraction of the public that is willing to respond;
    - F_c = fraction of the public that knows how to respond effectively and is capable of responding (or has someone to help them).

A new system with all required components and with a high probability of proper operation and maintenance will achieve an efficiency of perhaps 90%, and an incomplete, poorly operated and maintained system will have a much lower efficiency at 30%.

A simplified example is presented in the insert below (Carsell et al. 2004).

Examples of Flood Mitigation Valuation for Residential Contents

- Based on Magnitude of Annual Damages
    - Annual damages tabulated - $100m
    - Lead time of 12 hrs (5 ft depth) - reduces damages by 8% or $8m
    - Lead time of 24 hrs (5 ft depth) - reduces damages by 13% or $13m
    - Extra 12-hr lead time reduces damages by $5m
    - Assuming 80% efficiency then value is ~$4m
- Based on Number of Residences
    - Residential contents valued at ~$100K
    - Lead time of 12 hrs (5 ft depth) - reduces damages by 8% or $8,000
    - Lead time of 24 hrs (5 ft depth) - reduces damages by 13% or $13,000
    - Extra 12-hr lead time reduces damages by $5, 000
    - For 1,000 houses - value of the additional +12 hours lead time is $5k x 10,000 = ~$5m
    - Assuming 80% efficiency then value is ~$4m

3.3. Russian River Basin Example

The Russian River is a recognized flood concern in terms of recorded history. Data for this provide examples of flood mitigation benefit estimations. The Russian River watershed encompasses 1,485 square miles within Sonoma and Mendocino Counties, California (Figure 8). It is one of the most flood-prone rivers in the State because of the watershed’s unique geography and its proximity to the coast, which together produce climatologically heavy wintertime rainfall. The Russian River faces challenges related to flood threats and mitigation, water supply, maintaining endangered species habitats, water quality, and recreation.

Based on history of flood damages incurred:

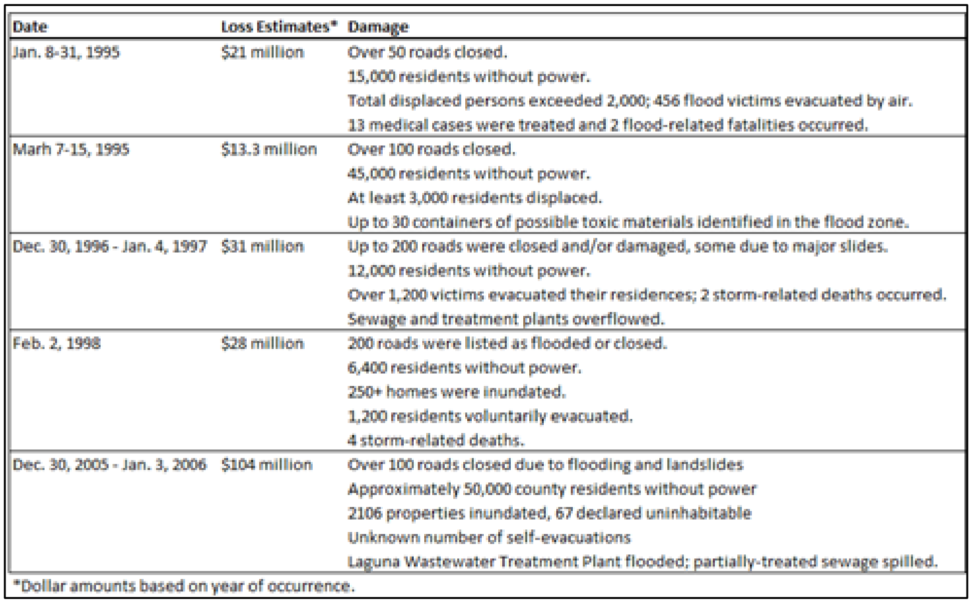
Table 3 summarizes recent flood events. Based on the data provided average annual damages for the period 1995 to 2006 are approximately $20M. Given a lead time increase from 12 hrs to 24 hrs, the Day method would project a reduction of damages from 25% to 30%; a 5% decrease in damages would be expected, or $1M on an annual basis. Assuming 80% response efficiency then the annual value is $800K. Taken over 10 years the present value (at 6% discount rate) of reduced flood damages is approximately $6M.

Based on structures in flood plain

The Sonoma County flood hazard report (SCWA 2011) noted that approximately 77 square miles, or five percent of the total unincorporated area of Sonoma County is within the 100-year flood zone designated by FEMA. Based on GIS analysis there are 3,511 addressed structures within the 100-year flood zone. Of these, records indicate that 802 are all or partially in the F1 Floodway zone with the remaining addressed structures are in the F2 zone. Some parcels with multiple structures may have more than one elevation permit on record. This suggests that at least 540 of the 3,508 addressed structures have been mitigated. Applying the Carsell approach for home contents damage reductions and assuming residential contents are valued at $100K, then a lead time increase from 12 hrs to 24 hrs decreases damages by $5,000 per household. For 3,000 houses the total potential reduction would be $15M on an annual basis; at 80% response efficiency the reduced damages would be $12M per year.

Figure 8 Russian River basin, CA

Table 3 Damages and estimated losses from recent flood disasters in Sonoma County (SCWA 2011)



Date	Loss Estimates*	Damage
Jan. 8-31, 1995	$21 million	Over 50 roads closed. 15,000 residents without power. Total displaced persons exceeded 2,000; 456 flood victims evacuated by air. 13 medical cases were treated and 2 flood-related fatalities occurred.
Marh 7-15, 1995	$13.3 million	Over 100 roads closed. 45,000 residents without power. At least 3,000 residents displaced. Up to 30 containers of possible toxic materials identified in the flood zone.
Dec. 30, 1996 - Jan. 4, 1997	$31 million	Up to 200 roads were closed and/or damaged, some due to major slides. 12,000 residents without power. Over 1,200 victims evacuated their residences; 2 storm-related deaths occurred. Sewage and treatment plants overflowed.
Feb. 2, 1998	$28 million	200 roads were listed as flooded or closed. 6,400 residents without power. 250+ homes were inundated. 1,200 residents voluntarily evacuated. 4 storm-related deaths.
Dec. 30, 2005 - Jan. 3, 2006	$104 million	Over 100 roads closed due to flooding and landslides Approximately 50,000 county residents without power 2106 properties inundated, 67 declared uninhabitable Unknown number of self-evacuations Laguna Wastewater Treatment Plant flooded; partially-treated sewage spilled.

*Dollar amounts based on year of occurrence.

3.4. *San Francisco Bay Region Example*

California's Flood Future Report

The report on California's Flood Future (CaDWR 2013) tabulated the number of structures in the 100- and 500-year flood plains (Table 4). The 9-county region has 126,000 structures in the 100-year flood plain and 373,000 structures in the 500-year flood plain. Assuming an average $100,000 value of contents per structure then the total potential contents damages are $12.6 B and $37.3 B respectively. With the 100-yr and 500-yr data points a damage-frequency chart can be plotted to support full spectrum damage-frequency curve estimation for each county. Figure 9 illustrates an example, and Table 4 tabulates the results. The EAD is computed by taking the area under the damage-frequency curve (Figure 9). Using this approach the total EAD for structure contents is estimated to be $250M per year for the 9-county area. It is this amount that can be used to estimate reductions associated with timely flood warnings. For example, if one adopts the 10% damage reduction level then the expected damages would be reduced by $25M per year. Attributing a 2% reduction as the incremental reduction for the AQPI system would save $5M per year. Taking a 10-year period and discounting at 6%, the incremental equivalent present value benefits of the AQPI system for structure contents damage reduction would be $37M.

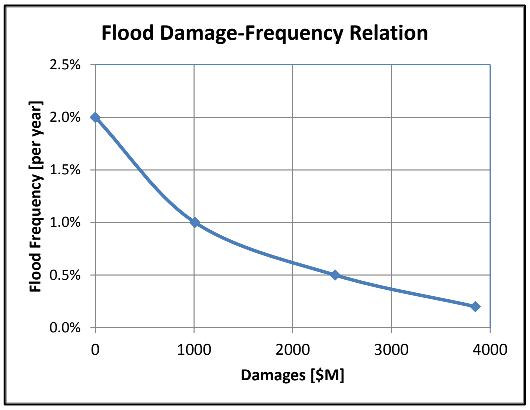


Figure 9 Flood damage frequency relation forms the basis for expected annual damage estimates.

Table 4 Expected annual damages to structures contents in SF Bay area

County	Structures in 100-yr Floodplain	Structures in 500-yr Floodplain	100-Yr Contents Damages* [$M]	500-Yr Contents Damages* [$M]	Exp. Annual Contents Damages [$M/yr]	Damages Avoided by 2% [$M/yr]	PV (6%, 10-yr) [$M]
Alameda	10,100	38,500	$1,010	$3,850	$23.1	$0.46	$3.4
Contra Costa	15,300	25,300	$1,530	$2,530	$23.4	$0.47	$3.4
Marin	13,300	22,100	$1,330	$2,210	$20.4	$0.41	$3.0
Napa	4,900	6,500	$490	$650	$7.0	$0.14	$1.0
San Francisco	0	0	$0	$0	$0.0	$0.00	$0.0
San Mateo	30,300	44,700	$3,030	$4,470	$44.4	$0.89	$6.5
Santa Clara	37,100	201,600	$3,710	$20,160	$105.8	$2.12	$15.6
Solano	7,200	23,100	$720	$2,310	$14.9	$0.30	$2.2
Sonoma	7,900	11,600	$790	$1,160	$11.6	$0.23	$1.7
Total	126,100	373,400	$12,610	$37,340	$250.6	$5.01	$36.9

* Assuming contents at $100K per structure (Carsell et al. 2004)

Ref: CaDWR 2013: California's Flood Future: Attachment D - Summary of Exposure and Infrastructure - Inventory by County

Storm Damages – the ARkStorm Scenario

The U.S. Geological Survey, Multi Hazards Demonstration Project (MHDP, Porter et al 2012) developed a detailed flood and impact scenario, called ArkStorm, which can be compared to the contents damage estimates presented above. HMT researchers (Ralph et al 2006) designed a large, scientifically realistic but hypothetical meteorological event similar to the intense California winter storms of 1861 and 1862 that left the central valley of California impassible. The storm is estimated to produce precipitation that in many places exceeds levels only experienced on average once every 500 to 1,000 years. In the San Francisco Bay area the ARkStorm was estimated to be in the 100- to 200-yr frequency level (Figure 10).

The MHPD (Porter et al 2011) tabulated impacts of the storm:

- In many cases flooding overwhelms the state's flood-protection system, which is typically designed to resist 100- to 200-year runoffs.
- The Central Valley experiences hypothetical flooding 300 miles long and 20 or more miles wide.
- Serious flooding also occurs in Orange County, Los Angeles County, San Diego, the San Francisco Bay area, and other coastal communities.
- Windspeeds in some places reach 125 miles per hour, hurricane-force winds. Across wider areas of the state, winds reach 60 miles per hour.
- Hundreds of landslides damage roads, highways, and homes.
- Property damage exceeds $300 billion, most from flooding.
- Demand surge (an increase in labor rates and other repair costs after major natural disasters) could increase property losses by 20 percent.
- Agricultural losses and other costs to repair lifelines, dewater (drain) flooded islands, and repair damage from landslides, brings the total direct property loss to nearly $400 billion, of which $20 to $30 billion would be recoverable through public and commercial insurance.
- Power, water, sewer, and other lifelines experience damage that takes weeks or months to restore.
- Flooding evacuation could involve 1.5 million residents in the inland region and delta counties.
- Business interruption costs reach $325 billion in addition to the $400 billion property repair costs, meaning that an ARkStorm could cost on the order of $725 billion.

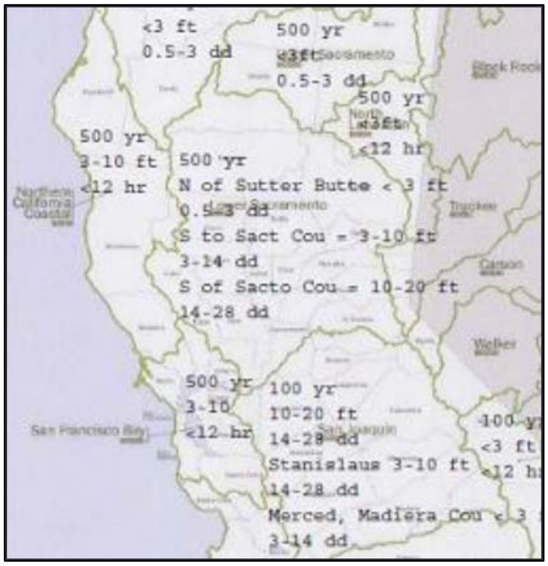


Figure 10 ARkStorm flooding parameter values, depth of flooding and length of time flooded (Porter et al 2011, Fig. 7, pg 10).

The ARkStorm exercise estimated flood-related damages for the 9 county San Francisco Bay region to total $105B and structure content damages at $35B (Porter et al 2012, Table 5). Application of the general flood damages avoided guidelines whereby a 12-hr lead time gets 10% damage reduction yields a potential contents damages avoided estimate of $3.5B. The (simplified) EAD for an assumed 100-year event is computed as 1/100 of the ARkStorm event content damages which yield $350M/yr as damages and $35M/yr damages avoided. More than ½ of these damages are associated with Santa Clara, Contra Costa and Alameda counties. The 5% damage reduction estimate totals to approximately $17 million per year; assuming a 10-year time frame the present value (at 6%) of these damages reductions total to $127 million. A more conservative assumption of 1% damage reduction for the incremental AQPI obtains an annual damage reduction benefit of $3.5 million per year and a present value equivalent over 10 years of $25 million.

Table 5 ArkStorm expected annual damages to structures contents using single frequency storm

County	Population (2005) [1]	ArkStorm Property Damages[2]	ArkStorm Content Damages[2,3]	100-yr Ann Eq[2,4]	Damages avoided [2, 5, 6]			
					5%	PV (6%, 10-yr) @5%	1%	PV (6%, 10-yr) @1%
Alameda	1,502,703	$14,000,000	$4,620,000	$46,200	$2,310	$17,002	$462	$3,400
Contra Costa	1,025,627	$16,000,000	$5,280,000	$52,800	$2,640	$19,431	$528	$3,886
Marin	252,988	$8,500,000	$2,805,000	$28,050	$1,403	$10,323	$281	$2,065
Napa	133,574	$2,000,000	$660,000	$6,600	$330	$2,429	$66	$486
San Francisco	796,150	$990,000	$326,700	$3,267	$163	$1,202	$33	$240
San Mateo	723,762	$11,000,000	$3,630,000	$36,300	$1,815	$13,359	$363	$2,672
Santa Clara	1,765,604	$40,000,000	$13,200,000	$132,000	$6,600	$48,577	$1,320	$9,715
Solano	420,246	$7,000,000	$2,310,000	$23,100	$1,155	$8,501	$231	$1,700
Sonoma	478,547	$5,500,000	$1,815,000	$18,150	$908	$6,679	$182	$1,336
Total	7,099,201	$104,990,000	$34,646,700	$346,467	$17,323	$127,501	$3,465	$25,500

[1] California Dept Finance (http://www.dof.ca.gov/research/economic-financial/)

[2] All values in $1000s

[3] Property content losses taken to be 1/3 of total property losses (Porter et al 2011. pg 91, 97 (Table 14)).

[4] Assuming ArkStorm as 100-yr event, then expected annual content damages at 1/100 listed.

[5] Assuming 12 hr lead time gets 5% contents damage reduction (expected response efficiency).

[6] Assuming 12 hr lead time gets 1% content damage reduction (low response efficiency).

4. RESERVOIR STORAGE FOR FLOOD CONTROL AND WATER SUPPLY

4.1. Storage Zones

Reservoir storage provides a basic means for capture of surface runoff and redistribution of the stored water over time and to various users. Reservoir volume for flood control involves reserved or empty space by which to capture flood runoff. Multi-purpose reservoirs typically have several zones including a conservation zone to meet water supply demands and other non-flood period purposes.

The NWS works very closely with operating agencies like the U.S. Army Corps of Engineers (USACE) to provide forecasts in exchange for reservoir scheduling information to produce hydrologic forecasts at key downstream damage centers. Through this cooperative venture, optimization of water-control projects during flood events is more attainable, resulting in substantial economic benefits that are attributable to both the NWS and USACE. The concept of forecast coordinated operations (FCO) has been advanced by the CNRFC for the Feather-Yuba flood control system (Hartman et al 2006).

USACE reservoirs are designed to safely accommodate the maximum possible flood while providing flood protection to areas downstream of the project. Each USACE flood-control project is regulated according to a prescribed operational schedule or "rule curve”. Figure 11 shows the “rule curves” for Lake Mendocino, CA which define the seasonal storage levels for flood control on top of the conservation zone.

Once reservoir levels reach a specific elevation, and downstream gages exceed or are forecast to exceed flood stage at the damage centers, an operational decision must be made to close the release gates and capture the flood waters. Allowing such capture is dependent on accurate forecasts of precipitation so that the flood threat is minimized. The amount of water "held out" represents the benefit of a structural measure and is compared to the water level that would have occurred under natural or pre-reservoir conditions. Then, for each damage reach, the difference in flood damage "with" or "without" conditions on the stage damage curve represents the benefits associated with that reservoir for that specific flood event for that one damage reach.

Nationwide, the USACE estimated the for the period 1977 to 1996 that flood damages prevented ranged from a low of $2.2 billion to a high of $39.4 billion, with an average annual estimate of $17.8

billion (all indexed to 1996 dollars). A conservative estimate is made that NWS hydrologic forecast benefits are equal to 5 percent of the average annual flood damage prevented by the USACE reservoirs (Stallings 1997). For a specific reservoir, quantification of the flood damage reduction value can be based on records of operations of the reservoir flood zone and simulation of stage reductions associated with such holdouts. The average annual combined economic flood loss reduction benefit from NWS hydrologic forecasts to the U.S. resulting from the U.S. Army Corps of Engineers and U.S. Bureau of Reclamation optimum reservoir operation is approximately $1 billion (all values in year-2000 dollars; NWS 2011b).

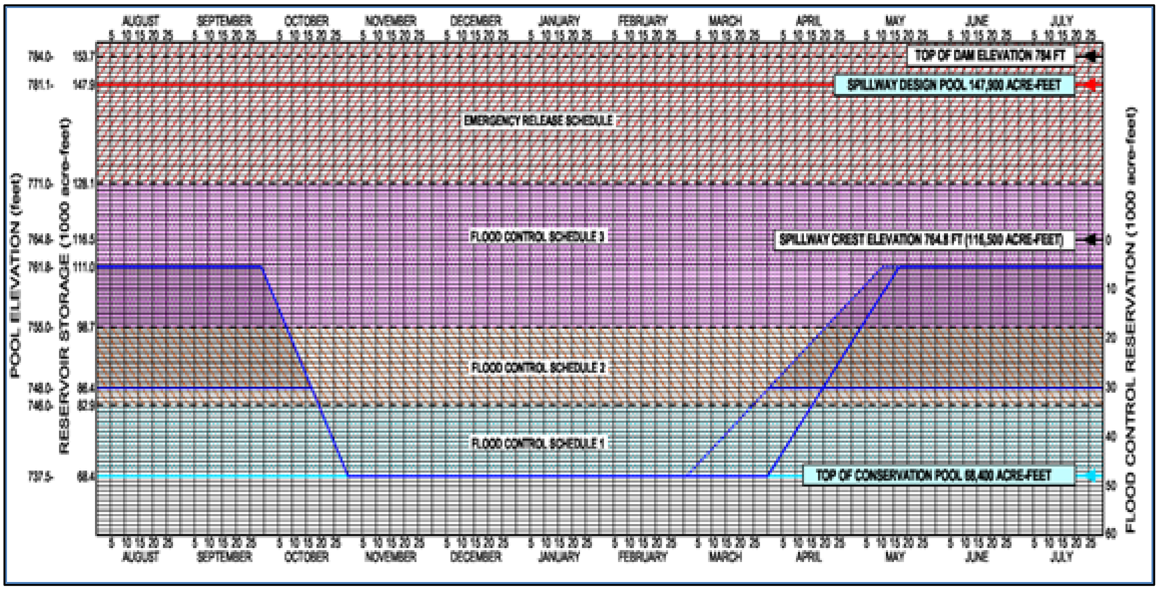


Figure 11 Lake Mendocino, CA rule curves definitions for flood zone operations. Each zone has associated storage and release criteria (USACE 2012).

4.2. Forecast-Based Operations

An emerging concept is that for forecast-based operations (FBO) in which decisions for flood control operations are based on forecasts of heavy precipitation events, or the lack thereof. FBO involves a more adaptive approach than the fixed rule curve approach. If a heavy precipitation event is forecast and imminent, then the reservoir storage level can be drawn down using a pre-release strategy. Here the flood storage volume is increased by incurring into the conservation zone with the understanding that the conservation zone can be refilled once the main rainfall event has passed. The reverse strategy is if there are no forecast heavy precipitation events, then the storage level would be allowed incur into the flood zone. If an event is forecast, then the flood zone could be evacuated; if no large event ever occurs, then the captured water could carry over into the non-flood season and be used to sustain water supply and other purposes. The FBO approach is also discussed below in Water Supply section.

In August 2002 the Corps Sacramento District proposed the modification of the current flood control (or “rule curve), diagram during mid- to late-spring, to define a flexible zone of operation around the allowable flood and water conservation storage lines (Pugner 2003). Definition of this flexible zone would be achieved by utilizing weather forecasts provided by the NWS. By anticipating runoff conditions 24-48 hours in advance, reductions in flow fluctuations and increases in spring runoff storage could be achieved resulting in a balance between fishery preservation and flood risk.

Benefits of FBO were described by Pugner (2003) using the Folsom Reservoir rule curve diagram. For the (former) Folsom Reservoir flood control diagram (Figure 12) the amount of required flood space varies seasonally from October 1st through the end of May. It also varies depending on how wet the basin is during the months of February, March, and April. The basin wetness is defined by a rain flood parameter that is computed daily from the weighted accumulation of seasonal basin mean precipitation by adding the current day's precipitation in inches to 97% of the parameter computed the preceding day. The required flood space is then determined by taking the computed rain flood parameter and interpolating between the defined lines on the diagram.

Pugner (2003) described the development of FBO procedures for operation of Folsom Reservoir and illustrated the storage benefits which could accrue with the modified approach. The Corps proposed a modification of the current flood control diagram (Fig 12), during mid- to late-spring, to define a flexible zone of operation around the allowable flood and water conservation storage lines. Definition of this flexible zone would be achieved by utilizing weather forecasts provided by the National Weather Service (NWS). By anticipating runoff conditions 24-48 hours in advance, reductions in flow fluctuations and increases in spring runoff storage could be achieved resulting in a balance between fishery preservation and flood risk. The example provided indicated in excess of 40,000 AF of water could be captured for later release to support water supply and fisheries purposes.

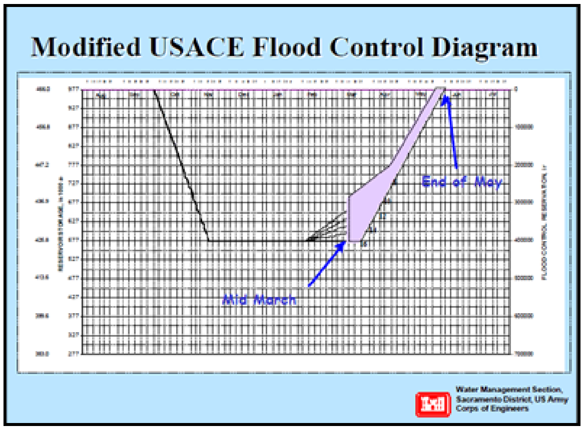


Figure 12 Modification of the Folsom Reservoir rule curves was proposed as a means to increase capture of conservation zone water during the early Spring season. (Pugner 2003).

A recent example of the utility of enhanced hydromet observations for flood-related reservoir operations is the HMT response to the Howard Hansen Dam situation in 2010 (White 2010). Before the HHD was constructed, floodwaters of the Green River periodically spread generally unimpeded across the GRV. Prior to the commissioning of the dam, the valley had flooded more than 30 times in 70 yr. Flood control provided by the HHD opened the way for increased development in the GRV. The valley is currently the home to the nation's fifth largest industrial park (second largest along the U.S. West Coast) and approximately 400,000 residents. The economic impact based on a flood scenario of 708 m^3/s (25,000 cfs) measured at the Green River stream gauge at Auburn, Washington (with no levee failures), is estimated to be $107 million per day, including 100,000 jobs with a $16 million daily payroll (Harris and Goodwin 2010).

After nearly 50 years of service providing flood risk management for areas near Seattle, the U.S. Army Corps of Engineers (USACE) discovered signs of a potential dam failure at Howard A. Hanson Dam (HHD) after a potent winter storm in early January 2009. The total economic impact of preventing flooding downstream of the HHD during this event was estimated to be $4 billion www.nws.usace.army.mil/PublicMenu/documents/HHD/D4-HHDFactSheetMarch2011.pdf). But the dam safety issue increased the risk of future catastrophic flooding in the now highly developed Green River Valley (GRV) downstream. As part of a broad set of actions by local, state, and federal agencies, the HMT implemented a rapid response effort involving additional rain gauges, three snow level radars, an atmospheric river observatory and a real-time water vapor flux tool (see http://www.esrl.noaa.gov/psd/data/obs/), and selected additional instruments. The HMT also applied numerical weather prediction (NWP) QPF models at higher space (~10 km) and time (~1 hr) resolutions than the standard NCEP products. A special web portal was created to display the HMT observation data and QPF products. Operational deployment of the HMT system was made for the 2009-2010 flood season and was credited for guiding reservoir operations to assure public safety and maximize capture of flood waters for later conservation uses.

Benefits of forecast-based operations (FBO) can be estimated using a systems analysis approach involving computerized simulation models to represent “with-“and ” without” operations rules. Such analysis involves a simulation model that accounts for the mass balance of reservoirs inflows, releases and changes in storage. The releases for downstream and off-stream uses, and storage limits are typically determined by operations “rules” which are pre-determined by the analyses to meet demands for water supply, flood control and other objectives. The flood control rule curves described above are one common example of how the rules may be enabled. There are many other kinds of operations rules that account for priorities of releases to different users and purposes, as well as to account for forecasts.

A recent study for the California DWR (MBK Engineers 2014) examined the potentials of FBO to increase capture of water supply while maintaining flood protection. Incorporation of weather forecasts allows for greater flexibility in the management of the reservoir’s space (flood control versus conservation, (Figure 13, Table 6). By reducing releases and allowing an increase in water storage into the formerly restricted flood zone during times when significant inflow volume to the reservoir is not predicted, significant improvements in water supply can be achieved. However, care must be taken so that sufficient water can still be evacuated in the event of a significant forecasted flood.

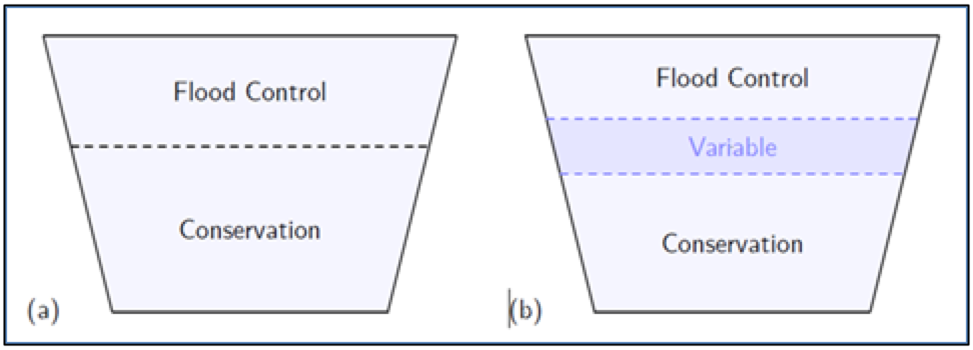


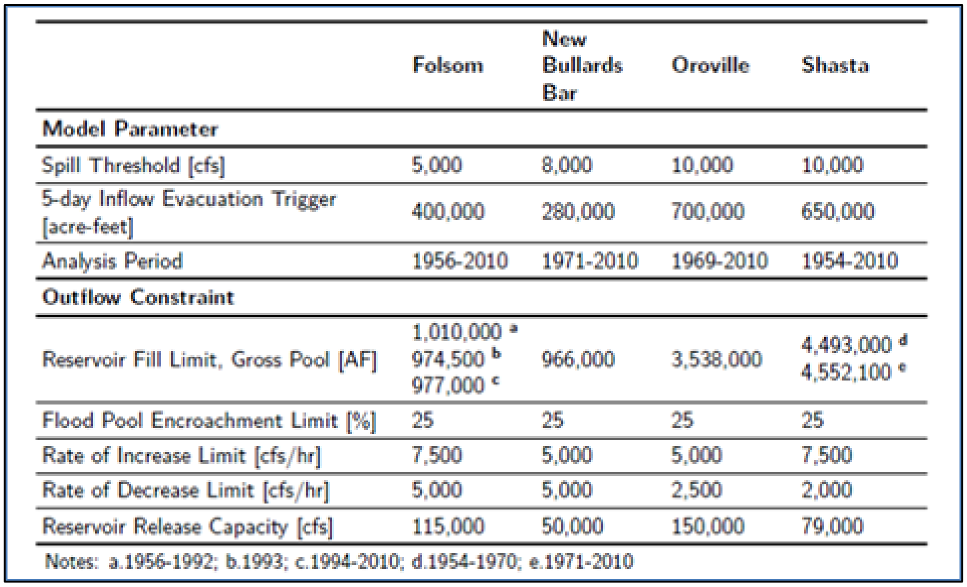
Figure 13 Depiction of reservoir space allocations under (a) typical operating paradigm and (b) forecast-based operation. (MBK Engineers 2014)

Assumptions used for the California FBO (MBK Engineers 2014) analysis involved the following:

- Daily Reoperation: Forecast-based system reoperation for the four reservoirs was analyzed in a daily operations model.
- Perfect Forecasting: The strong correlation between observed and forecast data justifies extending the reoperation methodology to real-time operations. The procedure should work equally well with uncertain forecasts in the real-time operational environment, provided the trigger levels are adjusted to account for forecast uncertainty.
- Reservoir Fill Constraints: Gross pool storage was used as the maximum reservoir storage constraint. For several of the reservoirs, the top-con curve has been revised over time. Thus, gross pool was noted each water year to set this constraint.
- Spill Threshold Values: A typical operation level for each reservoir was selected to provide a baseline outflow value for the reoperation routine. When the flood pool is encroached, typical reservoir operations procedures dictate that outflow should increase so as to draw down storage to the acceptable level (top-con).
- Flood Space Evacuation Targets: A flood space evacuation routine was written into the reoperation so that temporary storage could subsequently be evacuated if a large enough inflow was forecast. This process involved selection of 5-day accumulated inflow targets.
- Flood Pool Encroachment Constraints: Flood pool encroachment was limited to the maximum of either one quarter of the available flood space or the historical storage level. Outflow was required to exceed the rate necessary to maintain storage levels below the encroachment limit.

- Physical Constraints of Reservoir Facilities: Maximum reservoir outflow capacity and Rate of Increase (ROI) limitations were important for setting maximum limits on outflow, while Rate of Decrease (ROD) set the minimum outflow limit.

Table 6 Parameters for reservoir reoperation procedure (MBK 2014)



	Folsom	New Bullards Bar	Oroville	Shasta
Model Parameter				
Spill Threshold [cfs]	5,000	8,000	10,000	10,000
5-day Inflow Evacuation Trigger [acre-feet]	400,000	280,000	700,000	650,000
Analysis Period	1956-2010	1971-2010	1969-2010	1954-2010
Outflow Constraint				
Reservoir Fill Limit, Gross Pool [AF]	1,010,000 [a] 974,500 [b] 977,000 [c]	966,000	3,538,000	4,493,000 [d] 4,552,100 [e]
Flood Pool Encroachment Limit [%]	25	25	25	25
Rate of Increase Limit [cfs/hr]	7,500	5,000	5,000	7,500
Rate of Decrease Limit [cfs/hr]	5,000	5,000	2,500	2,000
Reservoir Release Capacity [cfs]	115,000	50,000	150,000	79,000

Notes: a.1956-1992; b.1993; c.1994-2010; d.1954-1970; e.1971-2010

Results of the DWR reoperations study (MBK Engineers 2014) showed that frequency of maximum reservoir storage was increased as follows: Folsom (12 of 55 years, 22%), New Bullards Bar (5 of 55 years, 9%), Oroville (10 of 55 years, 18%, Shasta (15 of 55 years, 27%).

Simulation models coupled with optimization procedures have been applied to identify reservoir FBO strategies that maximize conservation storage benefits and minimize flood risks. Shim, Labadie and Fontane (2002) presented a prototype decision support system (DSS) for integrated, forecast-based, real-time river basin flood control in a multipurpose, multireservoir system. A geographic information system is integrated with a database management subsystem, a real-time hydromet data monitoring system, a model-base subsystem for simulation and optimization, and a graphical dialog interface allowing effective use by system operators. An artificial neural network was employed in a real-time flood forecasting module to provide spatially distributed forecasted flows that are updated as the flood event progressed. Forecasted, basinwide discharges were input to an optimization model for determining real-time operational strategies, which were also updated as the flood event progressed. The DSS was applied to the Han River Basin in South Korea and demonstrated through simulated application to a severe 1995 flood event. Assuming no foreknowledge of the event, results show that forecast-based operational strategies generated by the DSS substantially reduce downstream flood impacts, while maintaining sufficient conservation storage for water use subsequent to the flood season. Other examples of the combined use of simulation and optimization involving FBO include those by Darsono and Labadie (2007), Lee and Labadie (2007) and Reiker and Labadie (2012).

4.3. Russian River Example

Operations of Lake Mendocino for flood control and water supply are a classic example of the competition between storage space reserved for flood storage and the volumes allocated for water supply in the conservation zone.

Historical storm events are illustrated (Figure 14). The March 2012 event involved capture and holding the runoff in storage for summertime releases. The 2012 event demonstrates the effectiveness of the optional rule curve to allow capture of later winter season inflows. The March 2011 storm event was one where reservoir inflows were not held in storage and were consequently lost downstream without refilling. Reservoir operations in March 2012 secured an extra volume of 20 KAF which carried into the summer season; the potential value for municipal water supply at $1000/AF is $20M.

Preliminary analysis of Lake Mendocino operations using a reservoir reoperations simulation approach was conducted by Johnson (2015, Figure 15). The ResOps model was applied using historical inflows and assuming these represent "perfect" forecasts, and the rule curves were modified to allow a 10-day look-ahead to support release decisions for: a) pre-release into the conservation zone if a large flood was anticipated, and b) flood capture if a small or moderate flood were to occur but no significant threat of additional flooding was anticipated. For the 10-year period 2002 to 2012, the revised FBO operations scheme was shown to yield an average storage increase of 10,000 AF/yr over the current operations using the fixed rule curve approach. Results presented in Figure xx) show an overall increase of monthly storage volume with an FBO operations policy. Further research on extreme flood events is required to properly address flood risk-performance issues.

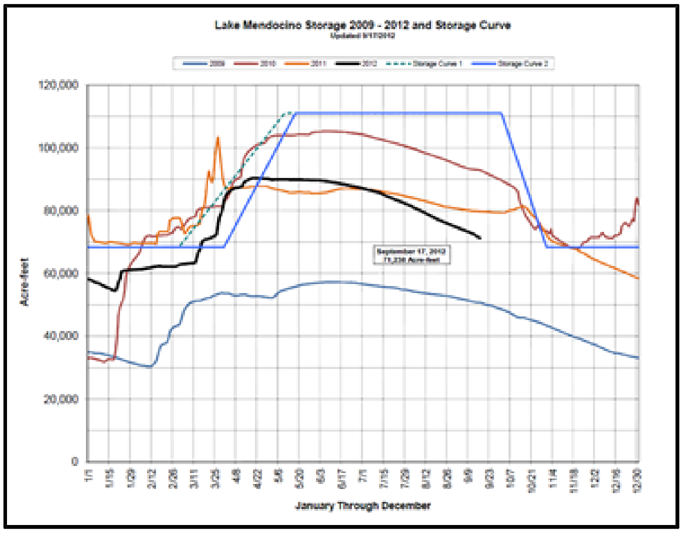


Figure 14 Lake Mendocino storage levels for several years' operation illustrate consequences of modified rule curves (pers comm C. Delaney 2012).

4.4. *Water Supply*

Water supply forecasts for municipal and industrial sectors range from the near-term (1 week to 3 months) to mid-term (6 months to over-year) to log-term climate-based forecasts. These forecasts allow water managers to make adaptive decisions for reservoir operations, delivery scheduling, and drought response actions. Similar actions are taken by irrigation water users, but in addition they can take make crop planting decisions based on snow pack levels, for example.

Short-Term Forecasts

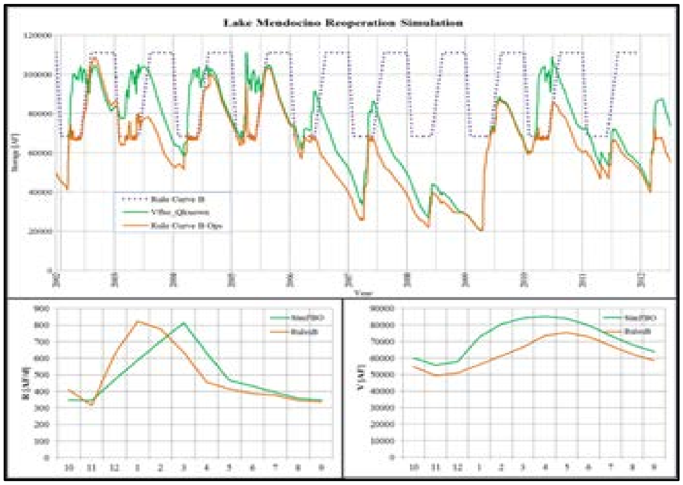


Figure 15 ResOps simulation for forecast-based operations (Johnson 2015).

Reservoir FBO can impact many of the water management applications, particularly in the short- and near-term time frames. FBO involves adaptive operations of reservoir storage and releases taking account of short- to near-term forecasts of inflows. Rather than strict adherence to fixed "rule curves" to determine releases, reservoir operators could take account of forecast inflows to anticipate storage levels in seeking to maximize overall benefits. Here, conservation storage may be allowed to incur into the reserved flood storage zone. If high inflows are forecast then the water levels can be drawn down so that flood protection is not sacrificed. Implementation of an FBO approach is constrained by administrative procedures for approval of operating rules, as well as the accuracy of precipitation forecasts.

Seasonal Forecasts

Seasonal stream flow forecasting, coupled with an adaptive reservoir operation policy, can improve decisions by water suppliers and watershed stakeholders (Gong et al 2010). Knowledge of future water supplies can be useful for equitably allocating water deliveries between urban, industrial, and agricultural users, as well as providing adequate releases for environmental and ecological needs. When the predicted flood risk is high, reservoir releases can be augmented to increase reservoir void space for flood mitigation. When the predicted drought risk is high, forecasts can be used as part of a formal or informal hedging and drought planning strategy to limit water supply risk.

The NWS RFCs issue seasonal water supply forecasts January through May based on precipitation as rain and snow (which accumulates); see CNRFC (2012) for example. These forecasts are for so-called "natural" flows on unregulated basins, but reservoir operators may provide feedback on stored waters and expected releases through coordinated operations. The methodology involves the Ensemble Prediction System (ESP) which produces long-range probabilistic forecasts of hydrologic variables. ESP utilizes a conceptually based modeling system to simulate soil moisture, snow pack, regulation, and stream flow. ESP then accesses the current hydrologic model states, and uses historical meteorological data to create equally likely sequences of future hydrological conditions, each starting with the current hydrological conditions. Statistical analysis is performed on these sequences to generate probabilistic forecasts of seasonal water supply. Future implementations will make use of the information available in the Climate Prediction Center estimation of precipitation and temperature to shift the forecasts based on our understanding of future meteorological conditions.

The value of the seasonal forecasts can be measured using various performance metrics. An example was presented by Gong et al (2010) for the New York City water supply. They used the number of drought emergency days that occur as the primary performance metric. Their evaluation involved hindcast simulations of a 57 year period of record using a reservoir operations model. Each year a SSF is issued on February 28, and used to inform any release policy modifications to be applied during the forecast period. Performance using the unaltered rule curves was compared to performance using modified operations curves. A reduction from 1,253 to 1,233 (1.6%) drought emergency days was demonstrated; this was characterized as a modest but tangible water management gain.

The values of water captured using an FBO approach are several. Various studies place differing prices on water. A CaDWR report (2009b) noted that as of 2006 the average price of treated water delivered to households was roughly $960 per acre-foot (in 2008 $). Depending on the region the price ranged from $545/AF (San Joaquin Valley) to $1,857/AF (Central Coast); the San Francisco Bay area price was $1,190/AF. Using a wholesale value of $1,000/AF the 10 KAF increase in storage would be valued financially at $10M per year. The CaDWR (2009b) noted that the value of most "field crops" (alfalfa, rice, corn, and various grains and legumes) is also relatively low on average - ranging from $200 to $600/AF of net water used, whereas fruits and nuts (mostly tree crops) average close to $2,000/AF. Vineyard water value would be higher than forage crops. Water captured in reservoirs also has value for ecosystem services. One way to value this is that the California Fish and Game are willing to purchase water to sustain fisheries (Herzog 2006); valued at $125/AF (dry period) to $25/AF (wet period). At these prices the value of increased fisheries flows during late summer dry periods would be $1.25M to $0.25M per year.

> "Improved capacity for designing and timing water releases will enhance riparian ecosystem structure and function due to establishment of a more variable hydrograph, restoring geomorphic processes and streamflow to benefit aquatic organisms from plants to salmon." CEMAR's Matt Deitch (pers comm 19 Mar 2014)

4.5. Hydropower

Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling (MEA, 2005).

Water also is a major source of energy. California relies on hydropower for between 15 and 30 percent of its annual electricity generation, depending on annual runoff and droughts (Madani and Lund 2009). The flexibility of hydropower makes it particularly valuable for meeting peak summertime demands. This resource will diminish if California's climate becomes drier, as less stream flow means less fuel for hydroelectric power plants. Hydropower management also has major implications for ecosystem health, because of the disruptions caused by dams and flow alterations to the aquatic environment.

Enhanced hydromet information can provide benefits for hydropower operations through more accurate mapping of watershed precipitation – both current and forecast. Researchers estimated the value of improved stream flow forecasts for Columbia River hydropower, derived from improved forecasting of the ENSO and PDO (Hamlet, et al 2004). Advances in climate forecasting have enabled forecasters to predict stream flows in the Columbia River basin six months earlier than forecasts that rely on actual snowpack measurements. Benefits from the improved forecasts were measured as the value of spot market energy sales that could result from improved stream flow estimates. It was estimated that these sales could increase annual revenue by approximately $161 million per year (in 2004 dollars).

Lee and Labadie (2007) applied the agent-based reinforcement learning method Q-learning to the Geum River basin in South Korea for determining optimal real-time reservoir operational strategies for maximizing hydropower generation, satisfying M&I and agricultural water supply requirements, and maintaining instream flow levels for riverine ecological enhancement. The Q-learning method was able to learn the complex underlying stochastic hydrologic characteristics of the basin without requiring explicit knowledge of complex stochastic models. Demonstration on the two-reservoir system show that optimal operating rules developed from Q-learning outperform those found from various stochastic optimization algorithms. Future enhancements include incorporation of real-time forecasts from hydromet information.

Table 7 Categories of benefits for ecosystem services

- **Production of Clean Water**
  - Avoided cost of sediment deposition
  - Reduced drinking water treatment costs
  - Avoided stormwater treatment costs
  - Reduced costs associated with TMDL compliance
- **Improved Water Supply**
  - Increased instream flow for environmental purposes
  - Increased water supply for municipal, agricultural and industrical purposes
  - Additional benefits associated with groundwater recharge
- **Maintenance of Salmonid Populations**
  - Value of increases in salmonid populations
  - Cultural and spiritual values of increased salmonid populations
- **Provision of Natural Capital for Recreation**
  - Improved quantity and quality of recreation
- **Improved Wetland and Riparian Habitat**
  - Increased or improved wetland and riparian habitat
- **Flood Regulation**
  - Avoided flood damage costs
  - Other benefits of avoided flood damages
- **Climate Regulation**
  - Avoided costs of climate change from carbon sequestration
- **Benefits of Investment in Built Capital**
  - Avoided electricity costs
  - Decreased operation and maintenance costs
  - Avoided costs of catastrophic failure and emergency repairs
  - Avoided costs of road maintenance
- **Benefits from Investments in Human Capital**
  - Reduced costs of future projects
  - Improvements in participants well-being
- **Benefits from Investments in Social Capital**
  - Reduced costs of future projects
  - Avoided water resources conflicts

5. ECOSYSTEM SERVICES AND RECREATION

5.1. Ecosystem Services

The Millennium Ecosystem Assessment (MEA 2005) defines and classifies ecosystem services into several categories (see insert). To avoid double counting of benefits the emphasis should be on final ecosystem services which is a component of nature, directly enjoyed, consumed, or used to yield human well-being. That is, final ecosystem services are outputs or end products of ecological processes that either directly result in human benefits or, when combined with human, social or built capital, produce human benefits (Table 7). These include provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling (MEA, 2005). Ecosystems provide both biocentric and anthropocentric types of services (DWR 2008). Biocentric (or biological) services are those that benefit the plants and animals inhabiting the ecosystem. Anthropocentric services are those that directly benefit humans such as maintenance of water supply quantity and quality, soil and air quality, floodwater storage, recreation, etc. These are the types of benefits emphasized here.

Weather-related ecosystem services were characterized by Cooter et al. (2013) to include aspects of precipitation that are directly consumed or enjoyed such as maintenance of drinking water supplies and recreational activities requiring a specific volume or depth of water such as swimming and boating. The service is measured in terms of precipitation depth or river flow volume. Such benefits are quantified by lake levels or the size of the recreational pool of a reservoir. The beneficiaries are the general and recreating public. Biocentric benefits are assigned for increased fish populations which provide increased fishing opportunities. Weather information was also associated with human benefits in terms of visitor enjoyment (number of visitors) and avoidance of safety and health threats (avoided emergency rescue expenses and hospitalization costs).

The Handbook for Estimating Economic Benefits of Environmental Projects (ECONorthwest 2012) described ecosystem benefit categories and the various methods for quantifying these values (Table 7). The report provided a general framework for identifying the benefits and costs of environmental enhancement projects. Various concepts were introduced, such as total economic value, ecosystem goods and services, and non-market valuation. Descriptions of common project activities were developed to illustrate how economic benefits arise for different types of projects. They then described in more detail how to quantify the value of or, alternatively, describe qualitatively from an economic perspective, each of the benefits.

Table 8 Economic value of Klamath Dam removals (adapted from Thompson 2012).

Ecosystem Service Benefits[1]	**$ millions**
Dam operations, maintenance, etc.	$ 189
Irrigated Agriculture	$ 30
Wildlife refuge recreation	$ 4
Troll Chinook fishery	$ 135
Ocean recreational Chinook fishery	$ 51
Inriver Chinook fishery	$ 2
Total Quantified Use Benefits	$ 410
Non Use Value	$ 15,645
Ecosystem Service Costs[2]	**$ millions**
Dam removal / mitigation	$ (166.80)
Klamath Basin Restoration Activities[3]	$ (472.10)
Foregone hydropower	$ (1,320.10)
Foregone reservoir recreation	$ (35.40)
Foregone whitewater recreation	$ (6.00)
Total quantified costs	$ (2,000.40)
Net Benefits (use values only)[4]	$ (1,590.50)
Net Benefits (use & non-use values)[4]	$ 14,055

[1] Non-quantifiable benefits: tribal fisheries, culture; steelhead and redband trout recreational fisheries; refuge bird watching; conflict resolution (KBRA)

[2] Non-quantifiable costs: CO2 emissions

[3] Klamath Basin Restoration Agreement (KBRA) includes fisheries, water quality, regulatory assurances, tribal and county programs

[4] Net benefits calculated with / without non-use values.

A detailed study of ecosystem service valuation was conducted for the proposed Klamath River dam removal project (see http://klamathrestoration.gov/). Table 8 lists ecosystem benefits for Klamath Dam removals. It provides an example of the types of benefits (and costs) and the relative magnitude. Noteworthy is that non-use values benefits are ~90% of service benefits.

The EcoNorthwest report (Reich 2012) provides useful guidance, and in some instances echoes the methods and metrics provided by others and used herein. For example, they described benefits for factors pertinent to precipitation forecasts and reservoir operations (Table 7). Also, the Handbook cites Loomis (2006) on the value of fish populations:

"Individuals derive value from increases in fish populations in two ways: some (e.g., recreational anglers, commercial fishermen, people who consume fish) derive benefits by catching, selling, and/or eating the fish. Others (including some from the former group) derive value from the salmon solely based on the salmon's existence. Studies have shown that regardless of direct interaction with salmon populations, many Californians hold a positive willingness to pay to ensure the long-term survival of salmon."

The Handbook notes that several studies have attempted to estimate the passive use value of increases in salmonid populations among households in California and neighboring states. At the per-salmon level, these studies reveal that households are willing to pay only fractions of a penny for increases in salmon populations. When summed across a region, however, the total value Californians are willing to pay for increases in salmon populations can become several thousands of dollars per fish (Table 9).

Table 9 Potential annual economic value of increases in salmonid populations.

Value Per Fish	Citation
$500	Olsen, Richards, and Scott 1991
$4,200	Loomis 1996
$9,300	Bell, Huppert and Johnson 2003

Enhancement of fisheries can be realized by releases from reservoirs to provide adequate flows for spawning and sustenance. The benefits of the FBO approach apply across conservation uses (water supply, hydro-power, ecosystem enhancement and recreation) given the potential for increased conservation storage. One way to assess the value is that the DWR Environmental Water Account (EWA) water price in 2005 was set at $125 per acre-foot for a "critically dry" year (Herzog 2006). For the Folsom Reservoir example, the FBO captured 40 KAF would be valued at least $5M (e.g. fisheries enhancement).

Many coastal ecosystems have been adversely impacted by increased storm-water drainage due to expanding urbanization, including the ecosystem of the St. Lucie Estuary (SLE) on the east coast of south Florida. Labadie and Wan (2012) describe a suite of models called OPTI7 dealing with watershed hydrology, reservoir optimization, and estuary salinity and ecology for optimal sizing and daily operation of storm-water reservoirs. Daily operations are based on nowcast information based on the South Florida Management District's extensive hydromet system. The multipurpose storm-water control facilities provide for hydrologic restoration for recovery of salinity-sensitive biota in the SLE, as well as supplemental irrigation water and pollution control through connected storm-water treatment areas.

5.2. Water-Related Recreation

The use and economic benefits provided by water- recreation can be substantial, although difficult to estimate because such use occurs over diffuse areas and is often not under the jurisdiction of one area or operator (CaDWR 1994). Natural river flows ordinarily occur only for a short period during a year, and popular areas with prolonged periods suitable for rafting often result from coordination with release schedules from major dams and reservoirs. Benefits for water-related recreation are often estimated by valuation of user days. For example a recreation user day has been valued at $30 which includes direct expenditures and value added and income; jobs are estimated at 4per 10,000 visitor days (Wiley et al 2006).

Hydromet forecasts support water-related recreation for hazardous events to reduce threats to loss of lives and damages. Storm forecasts alert boaters, fishermen and swimmers of potential threats so that they do not get caught in life threatening conditions. The benefit for recreational activities is the value received from safely enjoying the activity (Kite-Powell 2006). That value is the amount the recreator would be willing to pay for the opportunity to go to the water less the amount that is actually paid (usually transportation costs). If the recreator makes the trip only to find the beach closed or to find surf conditions too large or too small for enjoyable and safe use, then there is a loss of value.

Kite-Powell (2005) summarized that boaters' decisions potentially affected by forecast information include (a) the decision not to go boating on a given day because the forecast suggest that conditions are unfavorable, (b) the decision to go boating on a given day when they might otherwise not have because the forecast suggests that conditions are favorable, and (c) the decision to change the timing or destination of a boating trip. The value of decisions not to go boating is captured in part by consideration of boating safety benefits. Decisions of type (b) and (c) can be valued according to the economic surplus generated by a boating day in the region of interest. Here's the annual benefit can be related to the number of additional positive boating days per year due to the forecasts and the value associated with the boating day (willingness to pay less cost). The value of fishing and beach visits can be valued in a similar manner.

Capture and treatment of urban storm water and combined sewer flows is aided by hydromet forecasts, and thereby reducing water quality degradation in receiving waters. Benefits result from reduced beach closures which can be valued at the recreational user day rate of $30 per user day (Wiley et al 2006).

Darsono and Labadie (2007) developed a neural-optimal control model for real-time regulation of flows and in-line storage in combined sewer systems. A simulated real-time demonstration of the model was performed using the West Point Treatment Plant collection system of Seattle. Real-time control of in-line storage in a combined sewer network provides a cost-effective means of reducing pollutant-loaded, untreated combined sewer overflows to receiving waters. The neural-optimal control algorithm fully incorporates the complexities of dynamic, unsteady hydraulic modeling of the sewer system and optimal coordinated, system-wide regulation of in-line storage. A recurrent artificial neural network (ANN) is trained using optimal policies produced by a dynamic optimal control model for a range of historical overflow-producing storm events. Validation of the algorithm consists of simulating real-time control of a storm event not included in the training data set for the ANN. The ANN-based controller exhibits an effective adaptive learning capability from simulated real-time input of hydromet-based nowcasts that results in near-optimal performance of the control system while satisfying the time constraints of real-time implementation.

5.3. San Francisco Bay Recreation Example

Using the Tampa Bay study (Kite-Powell 2005) as a guide, it is estimated that between 10 and 50 percent of the recreational boating community around San Francisco Bay is aware of and (at least occasionally) making use of weather forecasts. About 9% of boaters surveyed in 2003-2004 indicated that they would like to have more or better information about weather (tide, wind, lightning, seas); and one third of these mentioned the internet as the preferred medium for obtaining this information (Sidman et al. 2004).

In 2007, California adults spent about 150 million days enjoying recreation activities directly dependent on water (CaDWR 2007). Many more days were spent in nature-based activities such as wildlife viewing (55 million adult participation-days), and hiking (36 million adult participation-days) In 2006, being one of the most popular pursuits among California travelers, beach and waterfront activities helped draw 366 million visitors making California the most visited state in the country. Projecting these participation rates to the San Francisco Bay area (7.4M/38M = 20%) results in an estimated 30 million water-related recreation days.

Boating

San Francisco Bay is the fifth largest port in the nation. An estimated 330,000 recreational boats are registered in the Bay region. The typical boater makes about 3.5 trips per month, averaged over the year – or 43 trips/year. Assuming that a boating day generates economic surplus equal to about 10 percent of actual expenditures (Hushak 1999), we estimate the per day surplus from recreational boating at $20/day. If AQPI data leads to a one percent increase in positive boating day experiences in San Francisco Bay, this suggests in annual non-market benefit from AQPI of $2.8M ($0.38/person/year).

Beach Visits

Typical expenditures directly associated with beach recreation are $25 to $30 per beach day, and generate an estimated $15 of consumer surplus per beach day (Pendleton 2004). Assuming that San

Francisco beaches are 10% of the California total of 366M visits yields 37M visits. Further assuming that one percent of San Francisco beach visits would be improved by the AQPI can lead to a one percent improvement in economic surplus generated by beach use. This suggests an annual benefit of $5M ($0.75/person/year).

6. WATER QUALITY

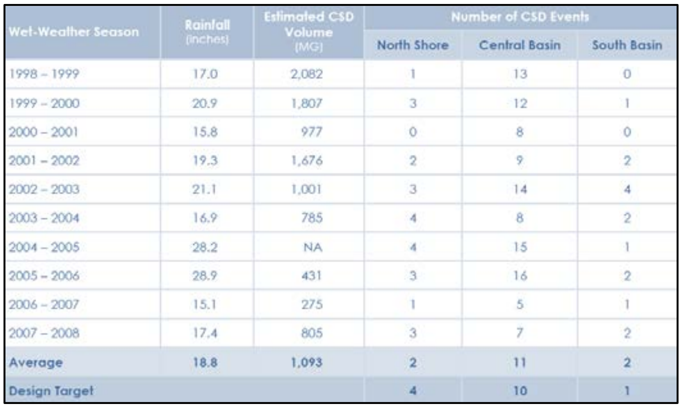
6.1. San Francisco Wastewater Example

The City and County of San Francisco has a unique storm water infrastructure that occurs in no other California coastal county -- a combined sewer and storm drain system (CSS). This system provides treatment to most of San Francisco's stormwater flows. During heavy rain events, the CSS can discharge combined treated urban runoff and sewage waste water. In an effort to reduce the number of combined sewer discharges (CSDs), San Francisco has built a system of underground storage, transport, and treatment boxes to handle major rain events. CSDs are legally, quantitatively, and qualitatively distinct from raw sewage spills that occur in communities with separate sewers. In addition to most CSS stormwater discharges being treated, they are also of much shorter duration and lower volume than discharges in communities with separate storm drain systems. Because of the CSS, San Francisco's ocean shoreline has no flowing storm drains in dry weather throughout the year. The city has a year-round program that monitors beaches each week.

Figure 16 San Francisco combined sewer system transport and storage boxes (from San Francisco 2030 Sewer System Master Plan 2011)

Major existing collection system facilities are illustrated in Figure 16. The transport/storage (T/S) boxes and tunnels ring the City like a moat around San Francisco's shoreline. The Bayside T/S collects wastewater from the east side of the City and ultimately routes flow to the Southeast Plant (SEP) during dry and wet weather seasons and to the NPF during wet weather periods. The ocean side system conveys water from the western side of the City to the Oceanside Plant (OSP). The three main functions of the T/S boxes are to capture combined storm water from the gravity collection system and prevent overflows into the coastal waters, store for later treatment, and provide a level of treatment by settling out grit prior to discharge into the coastal water when the systems storage capacity is exceeded.

Table 10 Bayside System combined sSewer discharges data (from CCSF 2010)



Wet-Weather Season	Rainfall (inches)	Estimated CSD Volume (MG)	Number of CSD Events		
			North Shore	Central Basin	South Basin
1998 – 1999	17.0	2,082	1	13	0
1999 – 2000	20.9	1,807	3	12	1
2000 – 2001	15.8	977	0	8	0
2001 – 2002	19.3	1,676	2	9	2
2002 – 2003	21.1	1,001	3	14	4
2003 – 2004	16.9	785	4	8	2
2004 – 2005	28.2	NA	4	15	1
2005 – 2006	28.9	431	3	16	2
2006 – 2007	15.1	275	1	5	1
2007 – 2008	17.4	805	3	7	2
Average	**18.8**	**1,093**	**2**	**11**	**2**
Design Target			**4**	**10**	**1**

Rainfall, CSD volume, and CSD events for the 10 wet-weather seasons from 1998 and 2008 are summarized in Table 10 (Bayside) (CCSF 2011). CSD durations were recorded at each discharge point, and discharge volumes were estimated using rainfall, runoff, and facility operating data. For this 10-year period, the discharge frequencies in the Bayside Central and South basins slightly exceeded the system design targets, while the discharge frequencies in the North Shore area are significantly below the design target. The average CSD frequency for the Westside met the design target of eight discharges per year.

Labadie et al. (1981) analyzed the value of real-time, short-term rainfall forecasting for operation of the North Shore Outfalls Consolidation Project. This study attempted to estimate what levels of rainfall forecast error can be tolerated before it is better to abandon adaptive control policies utilizing forecasts of various lead times in favor of reactive control methods based on nowcasts. Experiments with an autoregressive-transfer function model for short-term rainfall forecasting provided insights into expected forecast errors for selected untreated overflow-producing storms varying from high intensity-low duration to low intensity-high duration. These results were then compared with performance of the system utilizing a real-time optimal control model provided with rainfall forecast information for various lead times and levels of forecast error. Results indicated that expected forecast model errors are generally lower than the error threshold above which reactive policies become more attractive, indicating that rainfall forecasting is important for optimal combined sewer overflow control.

The SFPUC has the goal to minimize, to the extent possible, the number and volume of combined sewer overflows to the bay and ocean. Development and operation of the T/S system has greatly reduced the discharge of untreated sewage and stormwater in the Bay and ocean. Prior to implementing the T/S system there were frequent beach closures and fisheries habitat and water quality were severely impacted.

7. TRANSPORTATION

7.1. Overview

When the requirements of the transport sector in regard to weather information quality are being considered, all different transport modes (road, air, sea, rail, inland waterways) are relevant. The transport sector has always been highly weather dependent. Road transport has become increasingly weather reliant, not the least because of increasing traffic volumes and frequency of adverse weather events affecting the roads. Several major categories of weather information benefits are considered for the transportation sectors that include roads, sea ports, airports, railways, and pedestrian and bicycle ways.

- Improved safety
- Improved efficiency (e.g. travel time)
- Improved environmental protection
- Improved recreational experiences
- Science and educational

7.2. Roadways

A National Research Council report (2008) stated that the greatest impact of climate change for the U.S. transportation system will be flooding of roads, railways, the transportation system, and runways around coastal areas by the combined effect of sea-level rise and storm surges. Because San Francisco Bay has an extensive coastline (approximately 1,000 miles of shoreline), extreme weather events (such as severe storms or extreme precipitation), especially when exacerbated by sea-level rise will cause the high water levels and have substantial likelihood of being accompanied by sizable wind waves (Cayan et al. 2008). It is assumed that these events would produce the greatest impacts on California’s transportation infrastructure (Kahrl and Roland-Holst 2008). Very high seas and storm surge caused hundreds of millions of dollars in storm and flood damage in the San Francisco Bay Region in 1997–1998 (Ryan et al. 1999).

> Enhanced wx forecasts may guide road travel choices on timing and routes; although most drivers do not change. Enhanced wx could save $0.50/person/yr; incremental $.10/person/yr.

A study of sea-level rise and extreme storm events described impacts on the transportation infrastructure (Bigin, et al 2012, Table 11). A metric to assess change in the transportation infrastructure was the increased travel time from first responder locations to all neighborhoods. The loss of accessibility was the changes in travel time between these major nodes as influenced by an inundation model.

Table 11 Transportation impacts of sea-level rise and extreme storms on transportation (Biging, et al 2012).

Event Type	Potential Transportation Impact	Potential Operational Impact
Sea-level rise and storm surge	Coastal road flooding	Disruption of traffic, delay of evacuation and emergency response, increased congestion.
		Permanent breaks in the topological structure of the overall transportation network
	Railway flooding	Disruption of traffic, delay, increased risk of hazardous material spill
	Underground tunnels and subway flooding	Disruption and slowdown of subway traffic resulting in increased car, bus, and train commuting
	Erosion of coastal roads and rails	Potential road slump or failure, potential railbed instability or failure
	Port flooding and damage	Negative impact on commerce and manufacturing from delays in cargo handling
	Bridge scour	Erosion around bridge abutments or piers, adding to increased maintenance, potential failure
	Inundation of airport runways in coastal areas	Closure or slowdown in flight arrivals and departures, need for levee construction
	Higher tides at ports facilities	Erosion of shoreline, increased maintenance, need for levee construction, traffic disruption
Severe Storms	Damage to facilities at ports	Increased maintenance costs, periodic closures, and transshipment disruptions
	Greater probability of infrastructure failure	Closure or major disruptions and slowdowns in traffic
	Decreased expected lifetime of infrastructure	More frequent and extensive emergency evacuation
Increased Precipitation	Flooding of drainage systems, infrastructure	Increases in traffic disruptions and slowdowns, damage to infrastructure
	Landslides and mudslides	Increased traffic disruptions

Impacts on the transportation sectors were examined by Biging et (2012). It is evident that sea-level rise and flooding pose risks to the Bay Area's ports and airports, primarily because they are in low lying coastal areas. Even if these facilities are adequately protected by levees, dykes, roads, or other human-made barriers, for current climate conditions, there is increased risk of failure and overtopping as a result of projected SLR in combination with 100-year flooding. Figure 17 gives a broad view of the areas in the San Francisco Bay region projected to be impacted by a 100- year storm event in combination with either no sea-level rise or 1.4m sea-level rise.

Using a road network travel time modeling approach Biging et al (2012) also identified increases in travel time of first responders to all neighborhoods in the region (Figure 16). There is great loss and devastation to homes and fire stations themselves due to different levels of flooding events. However, while some local networks experience accessibility impacts, there is no dramatic or unexpected major loss of accessibility under potential inundation in the Bay region as a whole.

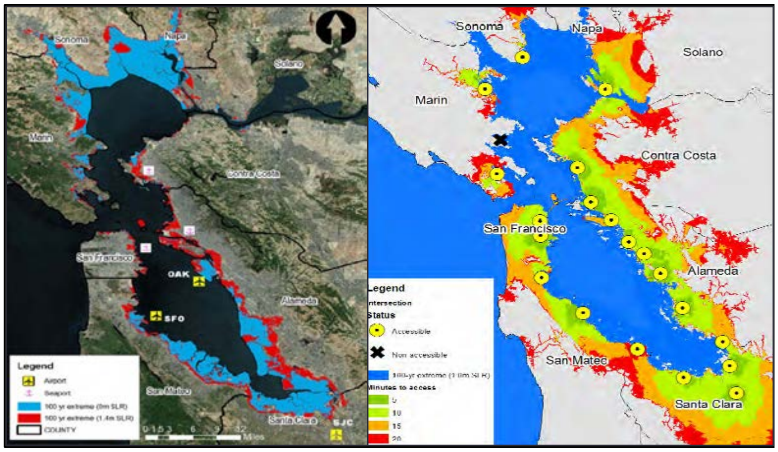


Figure 17 Roadway travel time delays associated with sea level rise and extreme storm event. a) (a) Locations in the San Francisco Bay area projected to be impacted by a 100-year extreme storm event without and with 1.4 m lea-level rise; b) Impacts on hinterland accessibility to major traffic corridor intersections by a 100-year extreme event with 1.0 m sea-level rise scenario (Biging, et al 2012).

7.3. Rail

Benefits of advanced forecasts for rail transportation is characterized in similar manner using costs avoided for delays. For the San Francisco Bay area, the BART system serves San Francisco, Alameda and Contra Costa counties. IT has a weekday ridership of 374,000 persons. BART has direct connections to two regional rail services: Caltrain, which provides service between San Francisco, San Jose, and Gilroy, at the Millbrae Station, and Amtrak's Capitol Corridor, which runs from Sacramento to San Jose, at the Richmond and Coliseum/Oakland Airport stations. Caltrain has a weekly commuter ridership of 47,000.

7.4. Ports

The PORTS study (Kite-Powell 2005) used formal economic procedures to estimate direct benefits of near-real time information and, in some cases, forecasts about water levels and currents at specific points in a coastal water body. The information made available by PORTS® results in economic benefits because it is used by decision makers to make choices that affect economic well-being. Kite-Powell noted that due to difficulties in estimation of consumer and producer surplus economists use other measures of benefit, such as the change in value added (contribution to GDP), or reduction in cost to achieve the same level of output. Usually, these measures are estimated as annual values at the level of a firm or other economic unit, and then aggregated over geographic regions and industries to estimate total annual benefits.

For the purpose of analysis, Kite-Powell (2005) used the following classification of benefits from PORTS® installations:

- Improved Safety of Shipping and Boating
    - Avoided groundings, commercial vessels
    - Avoided distress cases, recreational vessels
- Improved Efficiency of Marine Operations
    - Increased cargo carried per ship call (greater loaded draft)
    - Reduced delays (less allowance for error/margin in piloting decisions)
    - Improved SAR performance (surface currents)
- Improved Environmental Protection and Planning
    - Improved hazardous material spill response
    - Improved environmental restoration/conservation activities
- Improved Recreational Experiences
    - Enhanced value from boating decisions (power, sail, windsurfing, kayaking, etc.)
    - Enhanced value from fishing decisions
    - Enhanced value from beach visit decisions

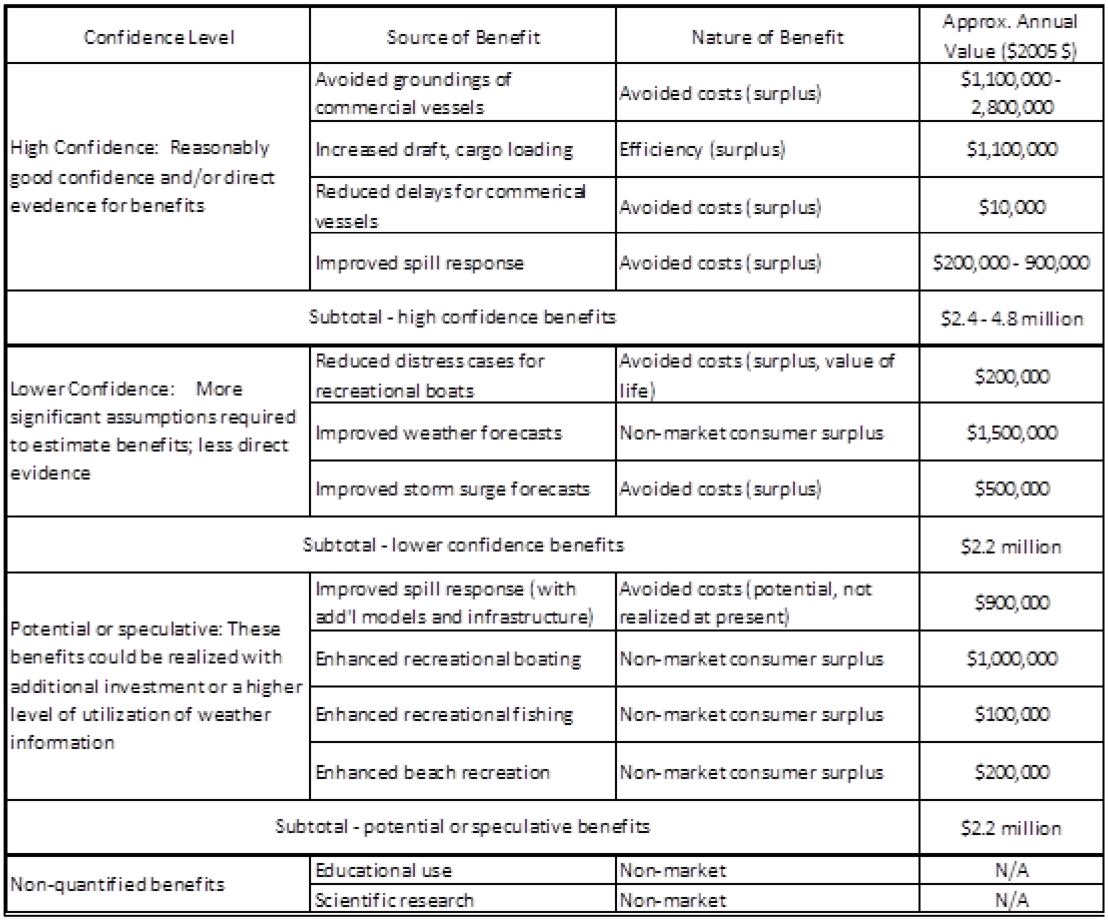
- Improved Weather and Coastal Marine Conditions Products
    - Improved general weather forecasts
    - Improved coastal marine weather forecasts
    - Improved storm surge forecasts
- Science and Education
    - Use of data in scientific research
    - Use of data in secondary education

Kite-Powell (2005) estimated the benefits of the PORTS® as summarized in Table 12; high confidence benefits at $2.4 – 4.8 million per year; lower confidence benefits at $2.2 million/per year and potential or speculative benefits at $2.2 million/year; total estimated quantifiable benefits were $6.6 – $9.0 million/year.

The exact contribution of PORTS® data to improved weather forecasts for the Tampa Bay area is not known. Using Lazo and Chestnut's (2002) estimate of about $15/household/year for the value of significant improvements to general weather forecasts, assuming that PORTS® data contribute 10 percent of such an improvement, for an estimated 1 million affected households, results in an annual benefit from improved weather forecasting of $1.5 million. This is considered a lower confidence estimate because although the mechanism is clear and the use of PORTS® data in this context is well established, the magnitude of the contribution of PORTS® to the weather forecast is difficult to quantify.

Major storm surge events hitting urban areas can cause billions of dollars in damages. *Assuming* a $1 billion storm surge damage from a major storm once every 20 years in the Tampa Bay area, Kite-Powell (2005) estimated an annualized risk from storm surge of $50 million per year. The precise contribution of PORTS® data to storm surge forecast quality and risk reduction is not known. Applying the one percent rule, they estimated an annualized value of $500,000 per year from improved storm surge prediction.

Table 12 Summary of estimated annual benefits from Tampa Bay PORTS® (Kite-Powell 2005).



Confidence Level	Source of Benefit	Nature of Benefit	Approx. Annual Value ($2005 $)
High Confidence: Reasonably good confidence and/or direct evedence for benefits	Avoided groundings of commercial vessels	Avoided costs (surplus)	$1,100,000 - 2,800,000
	Increased draft, cargo loading	Efficiency (surplus)	$1,100,000
	Reduced delays for commerical vessels	Avoided costs (surplus)	$10,000
	Improved spill response	Avoided costs (surplus)	$200,000 - 900,000
Subtotal - high confidence benefits			$2.4 - 4.8 million
Lower Confidence: More significant assumptions required to estimate benefits; less direct evidence	Reduced distress cases for recreational boats	Avoided costs (surplus, value of life)	$200,000
	Improved weather forecasts	Non-market consumer surplus	$1,500,000
	Improved storm surge forecasts	Avoided costs (surplus)	$500,000
Subtotal - lower confidence benefits			$2.2 million
Potential or speculative: These benefits could be realized with additional investment or a higher level of utilization of weather information	Improved spill response (with add'l models and infrastructure)	Avoided costs (potential, not realized at present)	$900,000
	Enhanced recreational boating	Non-market consumer surplus	$1,000,000
	Enhanced recreational fishing	Non-market consumer surplus	$100,000
	Enhanced beach recreation	Non-market consumer surplus	$200,000
Subtotal - potential or speculative benefits			$2.2 million
Non-quantified benefits	Educational use	Non-market	N/A
	Scientific research	Non-market	N/A

8. REGIONAL BENEFITS ACCOUNTING

8.1. Overview of Approach

The review of benefits estimation procedures were applied to the San Francisco Bay region in a spreadsheet for each of the categories and counties. Table 13 summarizes the categories of benefits and metrics adopted to compute direct benefits.

- General Hydromet Value: This category was retained to show the total values obtained using generalized factors and can provide a comparison to the values obtained by more detailed analysis below. These generalized values are not used for the B/C computation.
- Flood Mitigation: Benefits for avoided damages are estimated based on a 12-hr lead time, a 5% reduction in damages to structure contents (at $50K/structure), and a 60% response efficiency. Mapping of structures in the 100-yr and 500-yr floodplains by the CaDWR (2012) was the primary data source for the flood mitigation account. An incremental level of 1% reduction is assigned for the AQPI project in lieu of the 5% reduction for all weather services; this is the value used for the B/C computation.
- Water Supply: Benefits for captured water using reservoir forecast-based operations strategies are based mainly on the example application for Lake Mendocino. Information about reservoir storage volumes in Santa Clara County provided a basis for potential water capture in their reservoirs. Some ancillary capture for stormwater recharge where such operations are currently on-going was also accounted. Jurisdictions for which no information was available were not accounted. The level of benefits accounted for is considered to be lower than may be obtained as more detailed analysis for all jurisdictions may justify inclusion of additional FBO water supply benefits.
- Ecosystem Enhancement and Water Related Recreation: Ecosystem services benefits are difficult to quantify as these have been predominantly associated with “willingness to pay” metrics. Since this report emphasizes real monetary benefits then ecosystem services accounting can be said to underestimate total benefits. There are monetary benefits associated with valuation of reservoir FBO water capture which is complementary to water supply but valued at a lower rate. Avoided beach closures and value of recreational fishing are accounted using per-person rates.
- Transportation: Transportation benefits are accounted using per-person rates for the four sectors: road travel, aviation, rail roads and shipping. The per-person rates were based on various literature sources.

The regional benefits accounting approach is considered reconnaissance-level as it relies on general indicators for the most part and does not involve detailed data collections and economic analyses that might be applied for a more extensive study. Also, the regional accounting approach as applied is considered to yield partial and conservative estimates of benefits resultant from selection of factors in the lower range of those identified in the literature.

Table 13 Metrics for estimation of benefits of Advanced Quantitative Precipitation Information System.

Source of Benefits	Method	Data
General Hydromet Value	1% rule on economic activity	Retail sales (2007) [$billion]
	Per capita benefit	Value $286/person [population 1000s]
	Per capita benefit for early lead time	Value $14/person (incremental $5/person)[population 1000s]
Flood Mitigation	Lead time for residential contents	a) 12-hr lead time, b) 5% to 1% (incremental) reduced damages, c) $50K content value, d) 60% response efficiency. [# properties in 100-yr flood plain]
Water Supply	Captured water; anticipation of AR event at 5 days lead time.	Reservoir FBO can retain extra volume; estimated value for M&I water supply at $750/AF. [additional 1000 AF captured per year]
	Captured stormwater for aquifer recharge	Forecasts provide opportunity to capture stormwater for aquifer recharge; valued at $750/AF. [additional 1000 AF captured]
Ecosystem Enhancement	Fishery flows enhanced by FBO reservoir capture.	Reservoir releases to sustain fisheries enabled by FBO captured water; valued at $125/AF (dry period) to $25/AF (wet period). [1000 AF captured]
Water-Related Recreation	Reservoir releases support boating and fishing; severe wx warnings increase safety.	Visitor days per year for water-based recreation based on population ($1.20/person/year; incremental $0.60/person/year). [population in 1000s]
Transportation	Enhanced wx forecasts may guide road travel choices on timing and routes.	Enhanced wx could save $0.25/person; incremental $.10/person. [population 1000s]
	Aviation scheduling enhanced by wx information at hourly time scales.	Savings for advanced wx assigned as $0.50/person; incremental $.10/person. [population in 1000s]
	Rail operating efficiency, and safe and timely travel are influenced by wx.	Assign as $0.15/person; incremental $.05/person [population in 1000s]
	Shipping benefits include safety, efficiency, lower insurance, recreational boating.	Benefits of avoided shipping delays, grounding and spills, and surveys of shippers ($1.00/person; $0.50/person incremental). [population in 1000s]

8.2. Summary of Benefits

Application of the reconnaissance-level regional economic benefit accounting estimation methods is applied to each of the 9 counties in the San Francisco Bay region. Table 14 lists the total benefits tabulated for each sector. Appendix XX present the detailed tabulation for each county.

Table 14 Summary of benefits of Advanced Quantitative Precipitation Information System.

Source of Benefits	Method	General Value	Incremental Value	Confidence Level
General Hydromet Value	1% rule on economic activity	$1,132,000,000	--	Low
	Per capita benefit	$2,029,456,000	--	Low
	Per capita benefit for early lead time	$99,344,000	$35,480,000	Low
Flood Mitigation	Lead time for residential contents	188,850,000	37,770,000	Moderate
Water Supply	Captured water; anticipation of AR event at 5 days lead time.	$11,000,000	$8,250,000	Moderate
	Captured stormwater for aquifer recharge	$1,000,000	$750,000	Low
Ecosystem Enhancement	Fishery flows enhanced by FBO reservoir capture.	$1,500,000	$1,125,000	Moderate
Water-Related Recreation	Reservoir releases support boating and fishing; severe wx warnings increase safety.	$8,515,200	$6,386,400	Moderate
Transportation	Enhanced wx forecasts may guide road travel choices on timing and routes.	$3,548,000	$1,774,000	Moderate
	Aviation scheduling enhanced by wx information at hourly time scales.	$7,105,000	$1,776,250	Low
	Rail operating efficiency, and safe and timely travel are influenced by wx.	$2,128,800	$1,064,400	Low
	Shipping benefits include safety, efficiency, lower insurance, recreational boating.	$10,644,000	$3,548,000	Low
Total estimated benefits [$/yr]		$217,911,450		
Total incremental benefits [$/yr]			$62,444,050	

The general benefit tabulation (Table 15), based on indicators for the value of overall weather forecast services is estimated at $234M, of which $62M/yr may be assignable to the incremental benefits of the AQPI system. Assuming a 10-yr economic life and a 6% discount rate, the present value of the annual benefits total to $460M. This is the benefit value that is comparable to the AQPI development, installation and (discounted) operations costs.

Table 15 - Incremental annual benefits by category.

Benefit Category	Total Weather Forecast Benefits [$/yr]	AQPI Incremental Benefits [$/yr]	AQPI Incremental Benefits [PV(6%, 10 yr)]	% of Total Incremental Benefits
General	$1,120,154,000	$35,480,000	$261,135,889	
Flood Mitigation	$188,850,000	$37,770,000	$277,990,488	60%
Water Supply	$12,000,000	$9,000,000	$66,240,783	14%
Ecosystem	$1,500,000	$1,125,000	$8,280,098	2%
Recreation	$8,515,200	$6,386,400	$47,004,460	10%
Trans - Roads	$3,548,000	$1,774,000	$13,056,794	3%
Trans - Air	$7,105,000	$1,776,250	$13,073,355	3%
Trans - Rail	$2,128,800	$1,064,400	$7,834,077	2%
Trans - Port	$10,644,000	$3,548,000	$26,113,589	6%
Total for categories	$234,291,000	$62,444,050	$459,593,644	

Taken by category about 60% of the benefits are for flood damage mitigation ($37M/yr) with water supply (14%, $9M/yr), recreation (10%, $6.3M/yr), and transportation (14%, $8M/yr) following. The largest portion of the transportation benefit is for shipping.

It is important to acknowledge that many of the benefits associated with increased lead time are dependent on appropriate and adequate response by the hazards and water resources management agencies and citizens. This response "efficiency" involves designing and delivering the storm forecasts and warnings to meet user needs, and to conduct training and "table top" exercises to establish a foundation of understanding and preparedness.

Taken by county (Table 16) benefits for Santa Clara and Sonoma counties account for about one-half of the total for the region. For the whole region population these incremental benefits equate to about $8 per person per year. For Santa Clara County the major benefits accrue for flood damages avoided, while for Sonoma County the major benefits are for water supply obtainable with forecast-based operations.

Table 16 Incremental annual benefits for AQPI system by county.

County	Annual Benefits [$]	Annual Benefits [$/person]
Alameda	$6,111,150	$4.07
Contra Costa	$6,691,250	$6.52
Marin	$5,198,650	$20.55
Napa	$2,492,650	$18.66
San Francisco	$1,631,800	$2.05
San Mateo	$10,572,150	$14.61
Santa Clara	$16,998,250	$9.63
Solano	$3,021,000	$7.19
Sonoma	$9,727,150	$20.33
Total	$62,444,050	$8.80

Extending the present value comparison between the AQPI incremental benefits and the costs for system development and operations provides the basis for estimating the benefit – cost ratio (Table 17). Results of (partial) AQPI benefits tabulation to date show that the annual expected benefits total to $36M per year with a 10-year present value (at 6%) of $256M. For the total AQPI system costs, which includes federal and other regional expenditures, the total initial costs are $66M initial and $3.3M annual O&M; these compute to a present value cost of $90M and a B/C ratio of 2.8. If considering only the local costs of $33M initial and $3.3M/yr O&M, the present value cost is $57M and the B/C ratio is 4.5.

Figure 18 Benefits by category

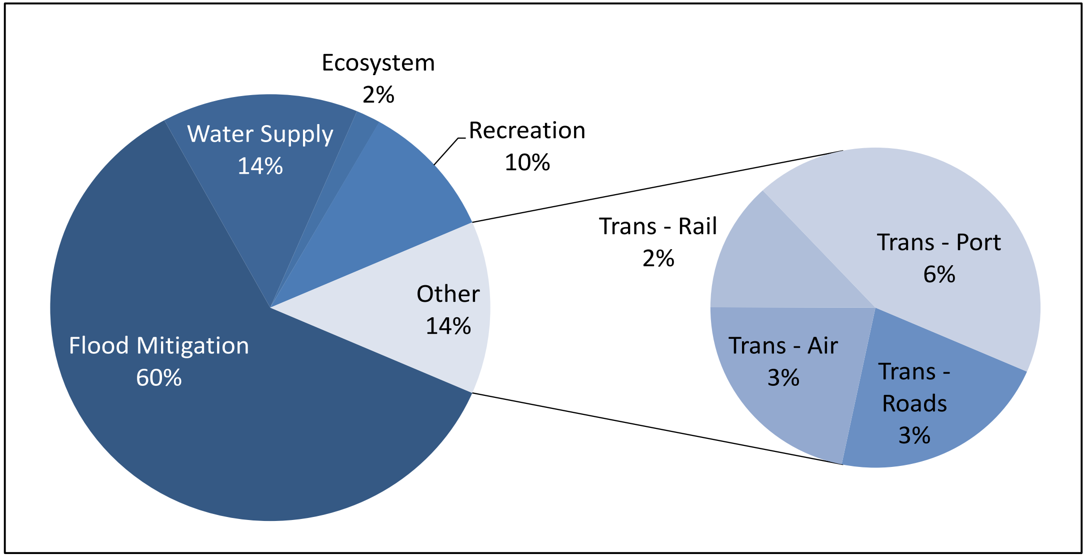


Table 17 - Benefit-cost summary.

	Initial Cost [$]	Anuual Benefit or Cost [$/yr]	Present Value (@6%, 10 yrs)	B/C
Benefits	--	$62,444,050	$459,593,644	
Costs (Total)	$66,000,000	$3,300,000	$90,288,287	5.1
Costs (Local)	$33,000,000	$3,300,000	$57,288,287	8.0

8.3. *Sensitivity of Benefit Estimates*

The benefit estimates presented above represent a "base case" or best estimate. It is of interest to examine how sensitive the estimates are to variations in the input factors. Table 18 lists the factors used for the sensitivity analysis, and the values assigned for the Base Case, High Case (optimistic), and Low Case (pessimistic).

- Flood Damage Reduction: Three factors were varied for this sector, a) household contents value b) % incremental damage reduction, and c) response efficiency.
    - The base case for household contents of $50,000 was increased to $100,000 (high) and decreased to $25,000 (low). The $100,000 level is the cited literature value.
    - The base case for % damage reduction of 1% was kept the same for the high case, and decreased to 0.5% for the low case. A 10% level is cited in the literature.
    - The base for response efficiency of 60% was increased to 90% (high) and decreased to 30% (low). As noted this factor is a prime indicator of community preparedness for flood threats and is a manageable metric by emergency preparedness programs.
- Water Supply: Several factors were varied for this sector, a) water capture using forecast-based operations, b) stormwater capture, and c) water value.
    - Water capture increase for the base case (7500 AF/yr) was based primarily on the details analysis for Lake Mendocino; this was increased to 10,000 AF/yr (high) and decreased to

    5,000 AF/yr (low). Small amounts of water capture were assigned to Santa Clara and other jurisdictions with the low case having zero capture. .
  - Small amounts of stormwater capture were assigned for jurisdiction currently conducting stormwater capture (1000 AF/yr base, 5000 AF?yr high, and 0 AF/yr low).
  - Water value for the base case ($750/AF) was increased to $1000/AF (high) and decreased to $500/AF (low). A value of $1000/AF and more was cited in the literature.
- Ecosystem Services: Two factors were varied for this sector:
  - Fish water value: The base case water value ($75/AF) was increased to $125/AF (high) and decreased to $25/AF. The $125/AF value was cited.
  - Recreational fishing: The base case value per capita ($0.90/person) was increased to $1.20 (high and decreased to $0.60 (low).
- Transportation: The four sub-sectors of transportation were all valued using per-person rates.
  - Highways: The base case of $0.25/person/yr was increased to $0.50/person/yr (high) and decreased to $0.10/person/yr (low).
  - Airports: The base case of $0.25/person/yr was increased to $1.00/person/yr (high) and decreased to $0.10/person/yr (low).
  - Trains: The base case of $0.15/person/yr was increased to $0.30/person/yr (high) and decreased to $0.05/person/yr (low).
  - Ports: The base case of $0.50/person/yr was increased to $1.00/person/yr (high) and decreased to $0.25/person/yr (low).

The total incremental benefits ranged from the base case ($62M/yr) up to $168M/yr (high) and down to $20M/yr (low). These translate to benefit/cost ratios of 5.1 (base), 13.7 (high) and 1.7 (low).

Table 18 – Sensitivity analysis summary.

Category	Variable	Base Case	High Case	Low Case
Flood Damage Reduction	Household contents	$50,000	$100,000	$25,000
	% Damage Reduction (incremental)	1.0%	1.0%	0.5%
	Response effciency [%]	60%	90%	30%
Water Supply	Sonoma capture increase [AF/yr]	7,500	10,000	5,000
	Santa Clara capture increase [AF/yr]	2,500	5,000	0
	Others' capture increase [AF/yr]	1,000	5,000	0
	Stormwater capture [AF/yr]	1,000	5,000	0
	Water value [$/AF]	$750	$1,000	$500
Ecosystem Services	Fish water value [$/AF]	$75	$125	$25
	Recreational fishing [$/person pop]	$0.90	$1.20	$0.60
Transportation	Highways [$/person/yr]	$0.25	$0.50	$0.10
	Airports [$/person/yr]	$0.25	$1.00	$0.10
	Trains [$/person/yr]	$0.15	$0.30	$0.05
	Ports [$/person/yr]	$0.50	$1.00	$0.25
Total incremental benefits from enhanced forecasts [$M/yr]		$62	$168	$20
	B/C Ratio	5.1	13.7	1.7

Tables 19-1, -2, 3 summarize detailed benefit estimates for each of the 9 counties in the San FRanciso Bay area.

Table 19-1 – Benefits tabulation for Alameda, Contra Costa and Marin counties.

Estimated Benefits of AQPI System County Tabulations		Alameda			Contra Costa			Marin		
Source of Benefits	Method	#	Gross Estimate [$/yr]	Incremental Benefit [$/yr]	#	Gross Estimate [$/yr]	Incremental Benefit [$/yr]	#	Gross Estimate [$/yr]	Incremental Benefit [$/yr]
General Hydromet Value	1% rule on economic activity	24.2	$242,000,000	NA	13.4	$134,000,000	NA	4.1	$41,000,000	NA
	Per capita benefit	1503	$429,858,000	NA	1025	$293,150,000	NA	253	$72,358,000	NA
	Per capita benefit for early lead time	1503	$21,042,000	$7,515,000	1025	$14,350,000	$5,125,000	253	$3,542,000	$1,265,000
Flood Mitigation	Lead time for residential contents	10,100	$15,150,000	$3,030,000	15,300	$22,950,000	$4,590,000	13,100	$19,650,000	$3,930,000
Water Supply	Captured water; anticipation of AR event at 5 days lead time.	0	$0	$0	0	$0	$0	0	$0	$0
	Captured stormwater for aquifer recharge	0	$0	$0	0	$0	$0	1	$1,000,000	$750,000
Ecosystem Enhancement	Fishery flows enhanced by FBO reservoir capture.	0	$0	$0	0	$0	$0	0	$0	$0
Water-Related Recreation	Reservoir releases support boating and fishing; severe wx warnings increase safety.	1503	$1,803,600	$1,352,700	1025	$1,230,000	$922,500	253	$303,600	$227,700
Transportation	Enhanced wx forecasts may guide road travel choices on timing and routes.	1503	$751,500	$375,750	1025	$512,500	$256,250	253	$126,500	$63,250
	Aviation scheduling enhanced by wx information at hourly time scales.	1503	$1,503,000	$375,750	1025	$1,025,000	$256,250	253	$253,000	$63,250
	Rail operating efficiency, and safe and timely travel are influenced by wx.	1503	$450,900	$225,450	1025	$307,500	$153,750	253	$75,900	$37,950
	Shipping benefits include safety, efficiency, lower insurance, recreational boating.	1503	$2,254,500	$751,500	1025	$1,537,500	$512,500	253	$379,500	$126,500
Total estimated benefits [$/yr]			**$18,193,575**			**$25,025,625**			**$21,162,325**	
Total incremental benefits [$/yr]				**$6,111,150**			**$6,691,250**			**$5,198,650**

Table 19-2 – Benefits tabulation for Napa, San Francisco and Santa Clara counties.

Estimated Benefits of AQPI System County Tabulations		**Napa**			**San Francisco**			**Santa Clara**		
Source of Benefits	**Method**	**#**	**Gross Estimate [$/yr]**	**Incremental Benefit [$/yr]**	**#**	**Gross Estimate [$/yr]**	**Incremental Benefit [$/yr]**	**#**	**Gross Estimate [$/yr]**	**Incremental Benefit [$/yr]**
General Hydromet Value	1% rule on economic activity	2.3	$23,000,000	NA	13.0	$130,000,000	NA	30.2	$302,000,000	NA
	Per capita benefit	133	$38,038,000	NA	796	$227,656,000	NA	1765	$504,790,000	NA
	Per capita benefit for early lead time	133	$1,862,000	$665,000	796	$11,144,000	$3,980,000	1765	$24,710,000	$8,825,000
Flood Mitigation	Lead time for residential contents	4,900	$7,350,000	$1,470,000	0	$0	$0	37,100	$55,650,000	$11,130,000
Water Supply	Captured water; anticipation of AR event at 5 days lead time.	1	$1,000,000	$750,000	0	$0	$0	2.5	$2,500,000	$1,875,000
	Captured stormwater for aquifer recharge	0	$0	$0	0	$0	$0	0	$0	$0
Ecosystem Enhancement	Fishery flows enhanced by FBO reservoir capture.	0	$0	$0	0	$0	$0	5	$500,000	$375,000
Water-Related Recreation	Reservoir releases support boating and fishing; severe wx warnings increase safety.	133	$159,600	$119,700	796	$955,200	$716,400	1765	$2,118,000	$1,588,500
Transportation	Enhanced wx forecasts may guide road travel choices on timing and routes.	133	$66,500	$33,250	796	$398,000	$199,000	1765	$882,500	$441,250
	Aviation scheduling enhanced by wx information at hourly time scales.	133	$133,000	$33,250	796	$796,000	$199,000	1765	$1,765,000	$441,250
	Rail operating efficiency, and safe and timely travel are influenced by wx.	133	$39,900	$19,950	796	$238,800	$119,400	1765	$529,500	$264,750
	Shipping benefits include safety, efficiency, lower insurance, recreational boating.	133	$199,500	$66,500	796	$1,194,000	$398,000	1765	$2,647,500	$882,500
Total estimated benefits [$/yr]			**$8,619,325**			**$1,611,900**			**$62,224,125**	
Total incremental benefits [$/yr]				**$2,492,650**			**$1,631,800**			**$16,998,250**

Table 19-3 – Benefits tabulation for San Mateo, Solano and Sonoma counties.

Estimated Benefits of AQPI System **County Tabulations**		**San Mateo**			**Solano**			**Sonoma**		
Source of Benefits	**Method**	**#**	**Gross Estimate [$/yr]**	**Incremental Benefit [$/yr]**	**#**	**Gross Estimate [$/yr]**	**Incremental Benefit [$/yr]**	**#**	**Gross Estimate [$/yr]**	**Incremental Benefit [$/yr]**
General Hydromet Value	1% rule on economic activity	12.4	$124,000,000	NA	6.0	$60,000,000	NA	7.6	$76,000,000	NA
	Per capita benefit	723	$206,778,000	NA	420	$120,120,000	NA	478	$136,708,000	NA
	Per capita benefit for early lead time	723	$10,122,000	$3,615,000	420	$5,880,000	$2,100,000	478	$6,692,000	$2,390,000
Flood Mitigation	Lead time for residential contents	30,300	$45,450,000	$9,090,000	7200	$10,800,000	$2,160,000	7900	$11,850,000	$2,370,000
Water Supply	Captured water; anticipation of AR event at 5 days lead time.	0	$0	$0	0	$0	$0	7.5	$7,500,000	$5,625,000
	Captured stormwater for aquifer recharge	0	$0	$0	0	$0	$0	0	$0	$0
Ecosystem Enhancement	Fishery flows enhanced by FBO reservoir capture.	0	$0	$0	0	$0	$0	10	$1,000,000	$750,000
Water-Related Recreation	Reservoir releases support boating and fishing; severe wx warnings increase safety.	723	$867,600	$650,700	420	$504,000	$378,000	478	$573,600	$430,200
Transportation	Enhanced wx forecasts may guide road travel choices on timing and routes.	723	$361,500	$180,750	420	$210,000	$105,000	478	$239,000	$119,500
	Aviation scheduling enhanced by wx information at hourly time scales.	723	$723,000	$180,750	420	$420,000	$105,000	487	$487,000	$121,750
	Rail operating efficiency, and safe and timely travel are influenced by wx.	723	$216,900	$108,450	420	$126,000	$63,000	478	$143,400	$71,700
	Shipping benefits include safety, efficiency, lower insurance, recreational boating.	723	$1,084,500	$361,500	420	$630,000	$210,000	478	$717,000	$239,000
Total estimated benefits [$/yr]			**$46,914,075**			**$11,650,500**			**$22,510,000**	
Total incremental benefits [$/yr]				**$10,572,150**			**$3,021,000**			**$9,727,150**

9. SUMMARY

Advancements in monitoring and prediction of precipitation and severe storms can provide significant benefits for water resource managers, allowing them to mitigate flood risks through better storm tracking and early warning, capture additional water supplies and offset drought impacts, enhance fisheries and ecosystem services, minimize water quality impacts from combined sewer overflows and storm water runoff, and minimize transportation system disruptions.

A case study for the San Francisco Bay area provides the context for quantification of the benefits of an Advanced Quantitative Precipitation Information (AQPI) system. The AQPI builds off more than a decade of research and applications of advanced precipitation sensors, data assimilation, numerical models of storms and storm runoff and systems integration for real-time forecast and warning operations. An AQPI would dovetail with the current NWS forecast operations to provide incrementally higher resolution monitoring of rainfall events and longer lead time forecasts.

AQPI development involves 4 phases. Phases 1 and 2 include a coastal Doppler weather radar which will point off shore to improve tracking of incoming low-level storms (1-6 hours lead time) and gap-filling radars (up to 1 hour lead time) which can provide high resolution coverage over populated and flood prone urban areas of the SF Bay region. Phase 3 would include additional gap filling radars and high resolution forecasts out to 12 hours. Phase 4 includes offshore reconnaissance and extended forecasts out to 3 days with emphasis on adaptive water supply.

Costs of an AQPI system occur in several categories for monitoring, analysis and assimilation, prediction modeling and system integration. Total startup costs are $33M with an equal amount already invested or planned for a total $66M. Annual operations and maintenance costs are estimated to be $3.3M/yr. Assuming a 10-year operations horizon the present value cost at 6% discount rate is $90M.

Decisions on investments to obtain an operational AQPI system require demonstration that the benefits exceed the costs. Estimation of benefits involves characterization of the spectrum of human and ecological activities in which Bay area residents participate, including avoidance of flood damages, maximizing water supplies, and enhancing ecological, recreational and transportation services.

A reconnaissance-level regional resource accounting approach has been developed to quantify AQPI benefits. The reconnaissance approach is considered partial and conservative in that detailed analysis was conducted for a few jurisdictions; additional study would likely reveal additional benefits.

Based on generalized indicators for the value of overall weather forecast services the total weather forecast benefits are estimated at $218M/yr, of which $62M/yr may be assignable to the incremental benefits of the AQPI system. Assuming a 10-yr economic life and a 6% discount rate, the present value of the annual benefits total to $460M.

Taken by category about 60% of the benefits are for flood damage mitigation ($37M/yr) with water supply (14%, $9M/yr), recreation (10%, $6.3M/yr), and transportation (14%, $8M/yr) following. The largest portion of the transportation benefit is for shipping.

Extending the present value comparison between the AQPI incremental benefits and the costs for system development and operations provides the basis for estimating the benefit – cost ratio. For the total AQPI system costs, which includes federal and other regional expenditures, the total initial costs are $66M initial and $3.3M annual O&M; these compute to a present value cost of $90M. Compared to present value benefit of $460M this computes to a B/C ratio of 5.1. If considering only the local costs of $33M initial and $3.3M/yr O&M, the present value cost is $57M and the B/C ratio is 4.5. Sensitivity analysis identified a range of B/C up to 13.7 and down to 1.7.

It is important to acknowledge that many of the benefits are dependent on appropriate and adequate response by the hazards and water resources management agencies and citizens. This response “efficiency” involves designing and delivering the storm forecasts and warnings to meet user needs, and to conduct training and “table top” exercises to establish understanding and preparedness.

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GLOSSARY

(adapted from Reich 2012)

Benefit. The well-being people derive from capital inputs, whether through active or passive consumption or appreciation merely through awareness.

Benefit-Cost Analysis. A systematic process for calculating and comparing benefits and costs of a project or policy. Also referred to as Cost-Benefit Analysis.

Bequest Value. A desire to preserve the environment for the benefit of future generations. See also passive-use value.

Built Capital. A stock of man-made physical resources, such as buildings; equipment; schools; roads; etc. See also, Capital.

Capital. Resources commonly used to produce things people value. See also, Human Capital, Built Capital, Natural Capital, and Social Capital.

Demand. Consumers' desire and willingness to pay for a specific good or service.

Discounting, Renders benefits and costs that occur in different time periods comparable by expressing their values in present terms. It reflects the fact that people prefer consumption today to future consumption.

Economic Value. A monetary measure of the benefit a person gains from a good or service.

Ecosystem Goods and Services. The aspects of ecosystems enjoyed, consumed or used, either actively or passively, to produce human well-being.

Existence Value. The benefit people derive from knowing a resource exists, e.g., knowing that the population of bald eagles hasn't gone extinct. See also passive-use value.

Human Capital. A stock of man-made knowledge resources, including: information; education; data; etc. See also, Capital.

Marginal. One additional unit of something.

Marginal Analysis. An examination of the additional benefits of an activity compared to the additional costs of an activity.

Market Benefit. The value of a good or service that is traded on a market (e.g., has a price assigned as people buy and sell the good or service).

Monetized Benefit. A benefit whose value is expressed in dollars.

Natural Capital. A stock of environmental and natural resources, such as forests, soil, air, and water. See also, Capital, Natural Resources.

Natural Resources. Elements of the natural world, such as forests, soil, air, and water. Commonly used to refer to those resources that can be used for economic gain. See also, Capital, Natural Capital.

Non-Market Benefit. The value of a good or service that is not traded on a market, but that contributes to people's well-being, e.g., a scenic view.

Non-Monetized Benefit. A benefit whose value is not expressed in dollars.

Option Value. The benefit people place on a future ability to use the environment, even if they are not currently using it.

Passive-Use Value. The benefit people derive from natural resources that they do not directly or indirectly use. These include existence value and bequest value.

Social Capital. A stock of man-made intangible resources, such as relationships; cultural, spiritual, and religious norms and values; and laws and regulations. See also, Capital.

Supply. The quantity of a certain good or service that producers are willing and able to sell at a given price. May also relate to the amount of an ecosystem service available at a given time and place.

Total Economic Value. The total value of a good or service. Includes Use Value, Passive-Use Value, Bequest Value, and Option Value.

Use Values. The benefit people derive from using natural resources. These can include direct use values, such as catching and eating a salmon and indirect use values, such as groundwater recharge that eventually provides drinking water.

Willingness to Pay. The amount a person would be willing to pay or exchange in order to receive a desirable good or to avoid something undesired.

APPENDIX A – ECONOMICS of HYDROMET INFORMATION

Various references have been used to describe the approaches to benefits estimation; citations are included where appropriate. A primary reference is a report by Kite-Powell (2005a) which describes a methodology for valuing the benefits from information provided by a Physical Oceanographic Real-Time System (PORTS®) installation; a companion report (Kite-Powell 2005b) applies the methodology to for Tampa bay. The Kite-Powell approach has been extended in this paper to include a broader spectrum of water resources purposes.

The most correct measure of benefit is the marginal increase in what economists call consumer and producer surplus (Kite-Powell 2005a, Fig A-1). Consumer surplus is the difference between what consumers are willing to pay and what they actually pay. Producer surplus is the difference between the price received for a good or service sold and the costs of producing that good or service.

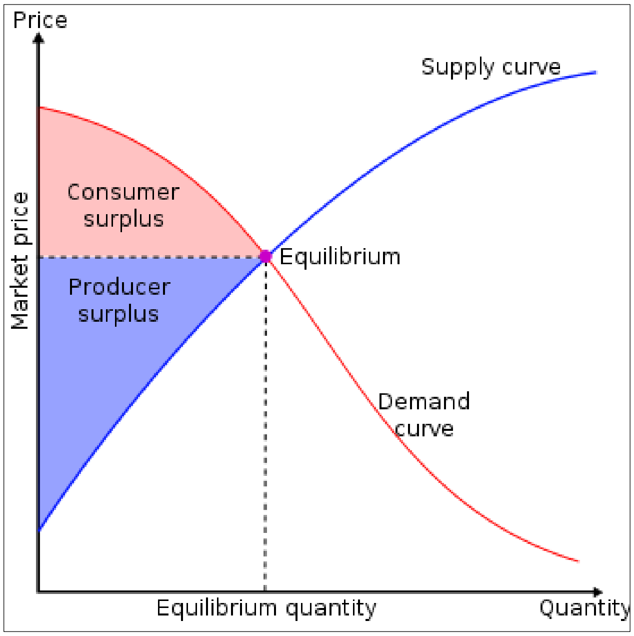


Figure A-1 Graph illustrating consumer (red) and producer (blue) surpluses on a supply and demand chart (Source: http://en.wikipedia.org/wiki/Economic_surplus)

The main products of hydromet services have "public goods" characteristics. In economics, a public good is a good that is both non-excludable and non-rivalrous in that individuals cannot be effectively excluded from use and where use by one individual does not reduce availability to others. Other examples of public goods include fresh air, national defense, flood control systems and street lighting. Once a weather forecast is produced, it is difficult to exclude users who do not pay for it. Thus private markets would not provide adequate forecasts, and public provision is appropriate. But private forecast tailoring and provision of other private specialized services do have a role to play, largely because of tailored responsiveness to consumer needs.

The problem with social surplus and both of its elements is that they can only be measured using exacting, time-consuming, and costly techniques. Other measures of economic activity (broadly termed "economic impacts") such as the value of sales at the wholesale or retail level, or value added (the most common example of which is the Gross Domestic Product, or GDP), are widely available, but measure social surplus in a rather imperfect manner.

In other situations, estimates of social surplus may be available but data to support an explicit model of how NWS/HMT information is used in economic decisions are lacking. In such cases, an order-of-magnitude estimate of potential value of NWS/HMT data may be obtained by applying a rule of thumb developed by Nordhaus (1996) and others: the value of weather and climate forecasts to economic activities that are sensitive to weather/climate tends to be on the order of one percent of the economic activity in question.

Because this surplus is often difficult to estimate, economists also use other measures of benefit, such as the change in value added (contribution to GDP), or reduction in cost to achieve the same level of output. These measures typically are less precise estimates of true social surplus. Usually, these measures are estimated as annual values at the level of a firm or other economic unit, and then aggregated over geographic regions and industries to estimate total annual benefits.

Studies of economic values from investments such as NWS/HMT thus often face a dilemma due to data constraints. The most appropriate measure is the least available, while the most available measures are the least appropriate. This is a major reason why these estimates of economic benefits often must be considered approximate.

Benefits represent only one side of the investment decision. To estimate net benefits, or rates of return, it is necessary to have information on costs as well (Kite-Powell 2005a). In the case of NWS/HMT, there are two main categories of costs: a) the cost of data collection, processing, and archiving; and b) the cost of generating from these data the products that decision makers ultimately use. In the case of NWS/HMT, the first component (the direct capital and operating cost of the NWS/HMT installation) is usually well understood. The second component generally includes activities carried out by both public and private sector organizations, and these costs are likely to be more difficult to specify. The analysis of costs associated with the generation and use of NWS/HMT data is described later in this report.

A product, such as a real-time precipitation map, represents information about the hydromet environment. This information has value when it can be used by an individual or organization to make a better decision – that is, a decision that results in an outcome that is economically superior. The standard economic approach to valuing information requires (Kite-Powell 2005a):

- A description of the information being valued and of the state of knowledge about the phenomena or conditions it describes. Typically, information is useful because it reduces uncertainty about the present or future state of nature in a particular context – for example, the location of a particular flood threat, or the exact water level on a flood plain.
- A model of how this information is used to make decisions. Most decisions are made in the face of imperfect information, or uncertainty about how conditions will in fact develop and what the exact outcome will be. For example, NWS/HMT data may be used in decisions involving avoiding flood damages. Here, the critical information concerns water depth, or other information needed for the safe and efficient evacuation.
- A model of how these decisions affect physical outcomes. Modeling the difference in outcome with and without the product in question usually requires making assumptions about how the decision makers will respond to the lack of the product in question.
- A model of how physical outcomes can be translated into economic outcomes. The value of a product is the difference between the expected value of the outcome of decisions using that product, and the expected value of the outcome without the product.

APPENDIX B – METHODS FOR ESTIMATING ECOSYSTEM VALUES

(adapted from King and Mazzotta 2003)

- **Market Valuation** — This relies on prices set by the buying and selling of a particular good or service. Established markets exist for some ecosystem services. For example, wetland-mitigation banks are publicly or privately managed lands that allow a developer or government agency to purchase mitigation credits that offset damage caused by construction projects elsewhere.
- **Replacement Cost** — Some benefits of projects that affect environmental resources can be estimated in terms of the costs society would have incurred without the projects. For example, a municipality may have in the past tapped a river for drinking water with little or no chemical treatment because high-quality riparian areas in the city's watershed maintained water quality. Over time, development degraded the watershed's riparian areas, which negatively affected water quality. As a result the municipality upgraded its water-treatment plant to filter and chemically purify the water. The additional filtration and purifying costs represent the replacement cost of the water quality services provided previously by natural riparian areas.
- **Avoided Cost** — Avoided costs represent the costs a community or some individuals would no longer incur if a project restores the ability of the environment to provide services or if the source of pollution is removed. For example, when a watershed's floodplain functions are restored and the risk of severe floods decreases, a community can benefit by avoiding damages to its properties.
- **Hedonic Analysis** — The basic premise of hedonic analysis is that the price of a good is related to its characteristics, or the services it provides, including environmental amenities. This method is commonly used to calculate that portion of a property's value attributed to the property's proximity to an environmental amenity, e.g., stream, forest, scenic view.
- **Travel Cost** — The fundamental principle of the travel cost method is that we can infer the value that people attach to an environmental asset based on the costs people will incur to access, use and enjoy the asset. For example, a travel cost analysis of a recreational fishery would calculate the value of the fishery based on fishing-related costs including: access fees, license costs, travel costs to and from the fishing site, costs of fishing equipment, etc.
- **Contingent Valuation** — This method estimates the economic value of a non-market benefit by directly asking a sample of consumers about their willingness to pay for a change in the level of an ecosystem good or service.
- **Benefits Transfer** — The benefit transfer method calculates the values of ecosystem services at a site (referred to as the policy site) based on the results from hedonic analysis, contingent-valuation, travel cost, or other studies conducted at a different location (referred to as the study site or sites).

APPENDIX C - FLOOD WARNING DIRECT TANGIBLE AND INTANGIBLE BENEFITS

Table C-1 Actions after Warning That Yield Direct Tangible Benefit

(Adapted from USACE 1994)

- Temporary removal of property from floodplain - Floodplain property owners can move belongings such as televisions, stereos, computers, important documents, and personal memorabilia.
- Moving property to a safe elevation within the floodplain - Residents and businesses occupying multi-story buildings may have the opportunity to protect moveable property by relocating it from basements and ground floors to higher levels.
- Temporary flood proofing - Warnings issued with sufficient mitigation time allow property owners to temporarily flood proof property with, for example, temporary closures of windows and doors.
- Opportune maintenance - A warning system can provide officials and individuals with more time to undertake opportune maintenance, such as closing a shut-off valve on a gas line, or safeguarding water supplies and sewage treatment plants.
- Early notification of emergency services - Increased warning time can reduce the cost of emergency shelter and emergency care as individuals have more time to arrange to stay elsewhere. The cost of public assistance and long-term emergency shelter for evacuees can be reduced if these evacuees have time to secure their property and prepare before evacuation. Communities with limited emergency personnel and other resources will benefit from additional time to ready emergency services.
- Orderly disruption of network systems - Warning and response systems offer opportunities for network systems (phone systems, utilities, pipelines, cable TV services, transportation patterns and traffic levels, and local area networks) to prepare for disruption in a more orderly and cost-effective manner. With sufficient warning time, businesses may make alternative plans for their network services.
- Suspension of sensitive works - For products that require lengthy production processes, sufficient warning time may provide the opportunity to suspend the production processes to minimize the destruction of the product or minimize the possibility of hazardous materials seeping into the waterways. Similarly, sufficient warning may allow crews to sequence repair work in a way that minimizes disruption to a utility.
- Related effects of emergency cost, cleanup cost, and business losses - Warning systems may reduce emergency costs and cleanup costs by allowing emergency responders and residents to take preventative actions. Similarly, warning systems may allow for reduced unemployment and income loss, smaller losses in sales, and smaller reductions in taxes collected by increasing the chances of a quick recovery. Also, the cost for flood insurance may be reduced as warnings result in decreases in the amount of coverage required by residents and businesses.
- Traffic control - Advance flood warning may provide the opportunity for authorities to decide which roads to close and which to keep open before flooding begins. Traffic can be re-routed in a more efficient manner and personnel can be deployed in a timely manner to block access to potentially dangerous areas as well as to direct traffic on detour routes.

Table C-2 Examples of Direct Intangible Benefits

- Protection of human health and safety - Flood warning and preparedness systems can result in the timely and orderly evacuation of a floodplain, which reduces risks to evacuees. The warning time is especially necessary for the evacuation of institutionalized populations in hospitals, nursing homes, schools, and prisons. Timely warnings would protect volunteers and emergency personnel by minimizing the need for them to conduct rescues.
- Incidental benefit from use of system for other disasters - Flood warning and preparedness programs may help put into place the process for dealing with other emergencies (earthquake, fire, storms, and hazardous materials accident). Once established, lines of communication and warning dissemination patterns have broad, long-lasting impacts.
- Reduction in impact of employment disruption - Warning systems provide time that allows firms to suspend business and prepare for the flood in a manner that would minimize the time and expense of getting back to business after the flood. Unemployment has been shown to cause an increase in crime, suicide, spousal and child abuse, and substance abuse of all kinds, increases in mental breakdowns, stress-related illnesses, and inattention to health problems. An effective response system may reduce these impacts.
- Reduced stress - Loss of life and injury can cause stress to the family of the victim and to the injured victim. Reducing the number of these events through warnings would lessen flood-related stress. The mere presence of a warning system provides many floodplain occupants with the reassurance that someone would tell them to act to protect themselves and their property. This reassurance would reduce stress.
- Reduction in family disruption - A warning system can provide authorities with the time to make better decisions about closing schools and other facilities. This would reduce family schedule disruption and associated chaos. Families would have more time to reunite and verify the safety of kin, thus reducing stress significantly.
- Benefit due to reduction of loss of memorabilia - Warning can provide the time and instruction necessary for people to gather and remove their most prized possessions, such as photographs, and memorabilia.

Table C-3 Examples of Indirect Tangible Benefits

Production benefit - Firms far from floodplains may have their fate tied to floodplain firms or services. For example, a restaurant owner who makes pasta sauce relies on a tomato farmer who is in a floodplain. If the tomato farmer's machinery is inundated, so that the crop cannot be harvested, the restaurant owner is impacted as well. Thus, the restaurant owner benefits indirectly from enhancements to the response system. With such physical or economic ties between floodplain and non-floodplain firms and activities, direct tangible benefits to floodplain firms and activities probably are accompanied by such indirect tangible benefits to non-floodplain firms.

Consumption benefit - Consumers who shop in, study in, recreate in, or otherwise use the floodplain would benefit from a more rapid recovery from flooding. Residents of non-floodplain properties may be dependent upon floodplain activities for their jobs. They would benefit from an enhanced response system. For example, a warning system could get an employee who works in, but does not live in, a floodplain back to work sooner. Likewise, an employee of a floodplain firm may avoid layoffs because a FWS permits actions that avoid loss of business.

Table C-4 Overview of NWS Weather Forecast Benefits (NWS 2011b)

- A recent report on NOAA’s economic statistics, “Value of a Weather-Ready Nation”, provides data on what is at risk and the value of NOAA’s NWS products (NOAA 2011b). For example, a nationwide survey (Lazo et al 2009) indicates that 96 percent of the U.S. public obtains, either actively or passively, 301 billion forecasts each year. Based on an average annual household value of $286 placed on weather information, the American public collectively receives $31.5 billion in benefits from forecasts each year. These benefits far exceed the $5.1 billion spent annually by both private and public weather bureaus on generating forecasts.
- A separate survey was conducted in states prone to hurricane damage to learn of the average taxpayer valuation of enhanced hurricane forecasts (Lazo et al 2010). Using current household tax obligation as the baseline value of current forecasts, researchers found that, on average, households in at-risk states were willing to pay an additional $14.34 per year to receive more precise hurricane predictions 48 hours in advance
- The NWS Climate Prediction Center provides El Niño Southern Oscillation forecasts. Annual benefits of El Niño Southern Oscillation forecasts to U.S. agriculture by altering planting decisions have been estimated to be in excess of $460 million (in 2010 dollars), throughout El Niño, normal, and La Niña years (Adams et al 1999). Annual benefits of El Niño Southern Oscillation forecasts to U.S. corn farmers from optimizing inventory storage costs could approach $240 million (in 1996 dollars) (McNew 1997). In the small northwest Coho salmon fishery, annual benefits of El Niño forecasts are estimated at $600,000 to $1.3 million (in 2010 dollars) from changing hatchery releases and harvest rates (Costello et al 1998).
- Prior to the 1997-1998 El Niño, California’s emergency management agencies and FEMA spent an estimated $219 million preparing for storms and heavy rain. Actual storm losses in the 1997-1998 El Niño were over $1.4 billion, compared to over $2.9 billion in damages as a result of the intense 1982-1983 El Niño. Although portions of the $1.5 billion difference are due to different intensities and durations of storminess during each El Niño, a significant portion of the savings came from heightened preparedness (all values in 2010 dollars) (Changnon 2000).
- A group of researchers estimated the value of improved stream flow forecasts for Columbia River hydropower, derived from improved forecasting of the El Niño Southern Oscillation and the Pacific Decadal Oscillation (Hamlet et al 2002). Benefits from the improved forecasts were measured as the value of spot market energy sales that could result from improved stream flow estimates. It was estimated that these sales could increase annual revenue by approximately $161 million per year (in 2004 dollars).
- River and flood forecast services are provided in the form of daily river forecasts by the 13 NWS River Forecast Centers (RFCs). Some RFCs, especially those in mountainous regions, also provide water supply volume and peak flow forecasts based analysis of snow pack in high elevations. Each of these forecast services are used by a wide range of decision-makers, including those in agriculture, hydroelectric dam operation and electricity generation, and water resource. Information from the RFCs is also the basis for local flood and flash flood warnings, watches, and advisories issued by the NWS Weather Forecast Offices.
- NWS also administers the Advanced Hydrologic Prediction Service (AHPS), which provides data to the public on the magnitude and certainty of occurrence of floods or droughts, hours, days and even months in advance of an event. Prior to AHPS, river forecasts were text products with 1-3 day lead times and were delivered via the weather wire.
- Factoring-in other water resources activities like hydropower, irrigation, navigation, and water supply conservatively adds another $523 million in benefits, bringing the total estimated annual benefits from improved long-range forecasting to $766 million. The average annual combined economic flood loss reduction benefit from NWS hydrologic forecasts to the U.S. resulting from the U.S. Army Corps of Engineers and U.S. Bureau of Reclamation optimum reservoir operation is approximately $1 billion (all values in year-2000 dollars).

APPENDIX D – FLOOD EXPECTED ANNUAL DAMAGE ESTIMATION PROCEDURE WITH EXAMPLES

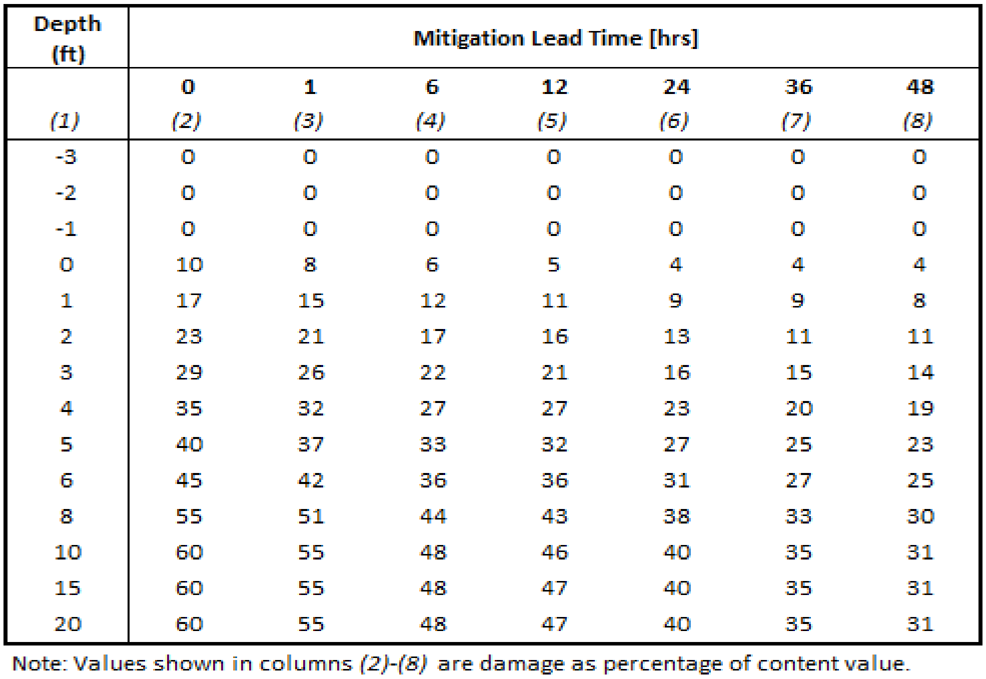
The EAD approach has been standardized in the U.S. Water Resources Council Principles and Guidelines (USWRC 1983) to account for the variability of damage due to floods of various magnitudes. The EAD computation commonly is accomplished by:

- Developing a water-surface elevation-probability (frequency) function for the location of interest, using principles of hydrology and hydraulics;
- Developing an elevation-damage function from information about location and value of damageable property in the floodplain; and
- Using the latter function to transform the former, thus yielding the required damage-probability function, this is integrated numerically to compute the EAD.

Damage-reduction measures alter the elevation-frequency function or the elevation-damage function, so the benefit of preventative actions taken with increased mitigation time can be evaluated. For example, temporary removal of property from the floodplain will alter the elevation-damage relationship, which will reduce the damage for a given probability and hence the EAD.

The Carsell et al (2004) method applied standard EAD computation procedures with the modified function, and then compared without-project and with-project damage to define the benefit. This approach is based upon opinions elicited from specialists in floodplain management and flood damage assessment Table D-1 presents values developed; these data effectively replace the Day curve values.

Table D-1 Residential Content Depth-Percentage Damage Relationship with Flood Mitigation Time (Carsell et al 2004)



Depth (ft)	**Mitigation Lead Time [hrs]**						
	0	**1**	**6**	**12**	**24**	**36**	**48**
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
-3	0	0	0	0	0	0	0
-2	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0
0	10	8	6	5	4	4	4
1	17	15	12	11	9	9	8
2	23	21	17	16	13	11	11
3	29	26	22	21	16	15	14
4	35	32	27	27	23	20	19
5	40	37	33	32	27	25	23
6	45	42	36	36	31	27	25
8	55	51	44	43	38	33	30
10	60	55	48	46	40	35	31
15	60	55	48	47	40	35	31
20	60	55	48	47	40	35	31

Note: Values shown in columns *(2)-(8)* are damage as percentage of content value.

The actual responses to flood warnings were addressed in the United Kingdom by Parker (1991). Factors considered to determine the actual flood damages avoided included:

- Fraction of residents available to respond to a warning,
    - If warnings are limited to ‘‘loudhailer’’ or siren warnings - 0.55;

    - In situations where ‘‘flood wardens’’ are used along with other warning methods - 0.65; with warning lead times of 6 to 8 hr - 0.80.
- Fraction of households who will respond to a flood warning or have others who will do so for them,
    - Without help from friends or family - 0.75;
    - With help from friends or family - 0.80.
- Fraction of households who respond effectively (0.70–0.95).

Example 1: No Mitigation Time in Without-Project Condition

The first example illustrates application of the proposed method to compute the inundation-reduction benefit for an impact area for which no effective mitigation time is available in the without-project condition. In this case, mitigation time is zero because the time required for notification and decision making exceeds the forecast lead time - the time between threat recognition and threshold exceedence. However, the computations for this case are identical to those required for a watershed for which no flood warning exists in the without-project condition.

The impact area of concern here is approximately 14.2 km^2 and could be inundated if levees protecting it are overtopped or fail. Total damages from the 500-year (0.002 annual exceedence probability) event would amount to approximately $2 million. The current level of protection is approximately the 100-year (0.01 annual exceedence probability) event.

Without-Project Damage. To compute the without-project damage, we use the elevation-frequency functions developed with hydrologic and hydraulic models (USACE 2002). We use the surveyed structure and content values, selecting the appropriate depth-damage function, depending on the mitigation time. For the impact area, state and federal forecasters estimate that with the existing warning system components, they can recognize a flood threat 12 h prior to threshold exceedence, on the average. Through systematic assessment of the available response plans, notification capabilities, and other warning and response capabilities for this impact area, it was concluded that 18 h are required for notification and decision making for this impact area. Therefore, because the notification and decision-making time exceed the forecast lead time, no time remains for mitigation.

To compute EAD, standard structure depth-damage functions were used. However, to estimate damage to content, we select and use the appropriate depth-damage function from Table 7. In this case, that is the function in column 2, which accounts for no damage reduction due to available mitigation time. The without-project EAD thus computed is $1,454,740.

With-Project Damage. With the proposed EFR&EP measures in place, forecasters estimate they could recognize a flood threat for this impact area 21 h prior to threshold exceedence, and the time for notification and decision making will decrease to 12 h. Thus, the mitigation time is 9 h, and damage will be reduced accordingly. By using the damage values from Table 7, interpolating as necessary, we find the with-project EAD with 9 h of mitigation time is $1,337,950.

Benefit. The total damage reduction for the impact area, and hence, the inundation-reduction benefit will be $116,790 if the enhanced system is fully efficient in this impact area. However, it cannot be. It is estimated that with the improvements the efficiency will increase to 0.81. Thus, the actual EAD reduction achieved is 81% of the predicted damage reduction, or $94,600.

Example 2: Mitigation Time in Without-Project Condition

Computing the benefit enhancements or improvements to an existing flood warning system is slightly more complex. In that case, computation of the without-project damage must consider the mitigation time and efficiency of the existing system. With-project damage is compared with this to establish the benefit. This is illustrated here with data from a second impact area from the Sacramento River basin. This impact area is 69.9 km2, and total damages from the 500-year (0.002 annual exceedence probability) event would amount to approximately $18,594,000. Flood damages begin to occur at approximately the 10-year (0.10 annual exceedence probability) event.

Without-Project Condition. Forecasters estimate that they can recognize a flood threat 18 h prior to threshold exceedence, and it was concluded that 15 h are required for notification and decision making. The difference, 3 h, is the mitigation time available in the without-project condition. The EAD with this mitigation time, using the values in Table 7 for content damage and interpolating as necessary, is $1,282,090. EAD with no mitigation time is $1,286,700. This investigation of available notification procedures and historical response to flood warning indicates that the efficiency of the current system is 0.60. Thus, the damage reduction of the current system is 0.60 of the difference between the damage with no mitigation time and the damage with 3 h mitigation time, or $2,766 annually. The without-project EAD is the damage with no mitigation time less the actual damage reduction, or $1,283,934.

With-Project Condition. With the EFR&EP measures in place, the mitigation time will increase from 3 to 10 h, and system efficiency will increase from 0.60 to 0.81. The EAD and resulting damage reduction of the system for this impact area would be $1,275,090 and $6,170, respectively, if the enhanced system was fully efficient. The actual damage reduction is $4,998. The with-project EAD is the damage with no mitigation time less the actual damage reduction, or $1,281,702.

Note that improvements in system efficiency increase damage reduction, regardless of whether mitigation time is increased. The with-project inundation-damage reduction is the without-project EAD (adjusted for efficiency) less the with-project EAD (also adjusted) for this impact area, or $2,232 annually.