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Remediation and water resource protection under changing climatic conditions

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HIGHLIGHTS

- Climate change uncertainty now impacts selection of water protection/remedies.
- Parametrization of uncertainties can aid in engineering and economic evaluation.
- Combined engineering/economic approach improves success for water management strategy.

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ABSTRACT

Our ability to develop reliable, cost effective solutions for remediation and protection of water resources has matured in recent decades due to various factors, including advances in engineering techniques, improved monitoring capabilities, and access to numerous case studies, historical datasets, and research to aid in the selection and evaluation of mitigation/remediation approaches. Traditionally, historical baseline conditions, and reasonable projections of future conditions provide significant input into the decision-making process. The variability, and unpredictable nature of climate change now requires that the inherent uncertainty of future conditions (both short- and long-term) be incorporated in our remedial decision-making. From an engineering perspective, this may include more flexible (and likely more costly) remedial designs, or a shift from current preferences for longer-term passive approaches to consecutive, shorter-term active alternatives. Incorporating an economic decision-making tool provides a means to parametrize the uncertainties associated with climate change, and may identify "tipping points" where our decisions may change. Different communities, whose interpretations of and costs of resource protection may acutely reflect their own unique cultural values, incomes, or beliefs in the future, can evaluate feasible engineering/water resource protection strategies even in the absence of certainty about future climate conditions. The combined approach merges evaluation of traditional engineering/performance metrics with an economic model that we anticipate will improve the success of water management strategies.

1. Introduction

The manifestation of short- and long-term climatic conditions should influence the design of reliable mitigation measures to protect groundwater and surface water resources. Predictions from leading national science affiliations, such as the US

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National Oceanic and Atmospheric Administration (NOAA, 0000) and the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO; Cleugh et al., 2011), suggest a continuing trend of high heat events and intense rain events, as well as less total rainfall, more rain than snow, and longer dry periods in arid and semi-arid areas such as California and much of Australia. For northern latitudes, including along the North Sea, organizations such as the European Environment Agency (EEA) are studying observed and potential impacts from climatic change and note that along with increases in temperature and changes in precipitation patterns, increased vulnerability to dramatic hydrologic events (coastal and inland) should be anticipated (Georgakakos et al., 2014). The conditions associated with these predictions will test our ability to develop effective and robust contaminant clean up and water resource protection measures that remain efficient, appropriate, and cost effective. Challenges may require additional engineering to compensate for potential variations in hydrologic conditions, inclusion of contingency approaches, or selection of shorter-term, active solutions that may be more costly than long-term passive solutions. Design may utilize more sophisticated predictive or realization-based numerical modeling to test different hydrologic scenarios for a given design or conditions. Further, making decisions among alternatives will need to involve these types of parameters, and a means of prioritizing between such uncertainties. The eventual decisions related to a design approach will have to consider whether mitigation or adaptation will be the most appropriate strategy to deal with the short- and long-term conditions associated with these environmental changes.

For low-lying coastal areas, the challenges associated with contaminant clean up and environmental protection coincident with rising sea levels and increased storm surge activity, which may result in temporary or long-term submergence of coastal environmental remediation sites, or may drastically alter the physical and chemical hydrologic conditions, will similarly require innovative design to assure long-term protection of water resources. Addressing these needs will require greater emphasis on assessing vulnerability, and ensuring that mitigation and protection measures are able to adapt to the effects of both acute and chronic hydraulic shifts.

The use of economic models that are parameterized by climate change scenarios should become more commonplace and drive decision-making on appropriate mitigation measures. However, history often shows that new decision-making approaches follow reactively, rather than proactively. In this paper, we consider the predictions concerning the influence of changes in the total climatic sphere (i.e., both above and below ground) on our current state of environmental and water resource conditions, and approaches to protecting sensitive water resources by introducing the principles of adaptive environmental engineering. Further, we provide a discussion and example where the application of economic principles was used to assist in the decision-making process to identify appropriate mitigation alternatives for improving the reliability of water management strategies.

2. Background and trends in climate change

The United Nations' Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC, 2014), predicted that climate change would result in: (1) increases in both incidence and length of heat waves; (2) increased intensity and frequency of extreme precipitation events; and (3) a rise in sea levels (with projections ranging from 0.2 to 1 m). NOAA has shown that these predictions have come true with the year 2015 showing greater numbers of long and intense heat waves, more frequent extreme storms, and the rate of sea level rise increasing over past two decades (NOAA, 2016). Freshwater resources are at substantial risk from coastal inundation, increased and unimpeded pumping of groundwater, and subsidence (which acts to decrease available storage in aquifer systems), and reduced snowpack, among other conditions. Climate change will reduce water quality as heavy rainfall increases sediment, nutrient, and pollutant loadings; droughts increase concentration of pollutants; and flooding disrupts treatment facilities. Due to forecasted sea level rise, coastal systems can expect to see submergence, coastal flooding, and erosion. Population growth, economic development, and urbanization will increase the human pressures on coastal ecosystems and exacerbate the impacts of climate change on coastal areas. Urban areas in particular will be impacted by heat stress, extreme precipitation, inland and coastal flooding, drought, and water scarcity.

Risks associated with climate change, as demonstrated by recent climate extremes (heat waves, droughts, and floods) "reveal significant vulnerability and exposure of [systems] to current climate variability" (IPCC, 2014). These impacts are significant for both developed and developing countries and demonstrate a "significant lack of preparedness for climate variability". The list of impacts due to climate change on water infrastructure is long and foreboding; it includes the increased risk of death and injury in coastal zones due to storm surges, coastal flooding, and sea level rise; the risk of ill-health and disrupted livelihood for urban populations due to flooding; the risk of breakdown in infrastructure and critical services due to increased incidence of extreme weather events; the risk of food insecurity due to warming, drought, flooding, and precipitation variability and extremes; the loss of marine and coastal ecosystems and biodiversity; and the loss of terrestrial and inland water ecosystems and biodiversity. Depending on emission pathways over the next century, the expected warming is projected to be between 2 and 5 °C. As the magnitude of warming increases, these impacts are exacerbated.

Europe's key risks from climate change also include increased economic losses from flooding driven by increased urbanization, rising sea levels, coastal erosion, and peak river discharges. Demand for groundwater for irrigation, energy and industry, and domestic use is expected to increase in Europe, which will increase water restrictions and reduce groundwater availability. Impacts from climate change have been observed in the main biogeographic regions in Europe, and include environmental (decreasing biodiversity, increased ocean temperatures and acidity, increased desertification, more forest fires, etc.) and economic (changes to tourism, decrease in hydropower demand, decrease in crop yields, intensified oil and