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ORIGINAL ARTICLE

Integrating a climate change assessment tool into stakeholder-driven water management decision-making processes in California

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Abstract There is an emerging consensus in the scientific community that climate change has the potential to significantly alter prevailing hydrologic patterns in California over the course of the 21st Century. This is of profound importance for a system where large investments have been made in hydraulic infrastructure that has been designed and is operated to harmonize dramatic temporal and spatial water supply and water demand variability. Recent work by the authors led to the creation of an integrated hydrology/water management climate change impact assessment framework that can be used to identify tradeoffs between important ecosystem services provided by the California water system associated with future climate change and to evaluate possible adaptation strategies. In spite of the potential impact of climate change, and the availability of a tool for investigating its dimensions, actual water management decision-making processes in California have yet to fully integrate climate change analysis into their planning dialogues. This paper presents an overview of decision-making processes ranked based on the application of a 3S: Sensitivity, Significance, and Stakeholder support, standard, which demonstrates that while climate change is a crucial factor in virtually all water-related decision making in California, it has not typically been considered, at least in any analytical sense. The three highest ranked processes are described in more detail, in particular the role that the new analytical framework could play in arriving at more resilient water management decisions. The authors will engage with stakeholders in

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these three processes, in hope of moving climate change research from the academic to the policy making arena.

Keywords Climate change · Hydrologic models · Stakeholders · Water planning · Water resource planning models

Background

The two central challenges in California water management are: (1) to overcome the spatial and temporal mismatch between where and when the precipitation occurs and where and when needs arise to use water, and (2) to balance the competing needs for water for off-stream uses in agriculture and urban areas, and for in-stream use for aquatic ecosystems. In California, the mismatch of demand with supply reaches dramatic proportions: two thirds of the state's precipitation occurs north of Sacramento, while over two thirds of the state's water use occurs south of Sacramento; in addition, over 80% of the total precipitation occurs between October and March, while about 75% of all water use in California occurs between April and September. The challenge is, thus, to ensure that water is available in the right place and at the right time for both humans and ecosystems.

Since work by Gleick (1987), Lettenmaier *et al*. (1991) and others, it has been recognized that climate change in California could exacerbate both of these problems. Climate change is likely to cause more winter precipitation to fall as rain than snow and to lower the water content of the snow on the ground, leading to an increase in winter runoff as a fraction of total runoff, an increase in the frequency of winter floods, and an earlier start of spring snowmelt. In the absence of additional storage, these changes would have the effect of reducing the state's effective water supply. A large volume of subsequent research has generally reinforced these conclusions, including recent work by Dettinger and Cayan (1995), Glieck and Chalecki (1999), Miller *et al*. (2003), Lund *et al*. (2003), Brekke *et al*. (2004), Dettinger *et al*. (2004), Stewart *et al*. (2004), and VanRheenen *et al*. (2004). Moreover, there is evidence that some of these changes are already under way, with clear signs of a warming trend in California over the past two decades (Dettinger *et al*., 2004) and the peak snowmelt runoff now occurring one to three weeks earlier in various watersheds of the Sierra Nevada.

Most analyses of the effects of climate change on the California water system are based on simulations of global climate change prepared for use in the 2001 report of the Intergovernmental Panel on Climate Change (IPCC). The newest results from two of the major General Circulation Models, the Hadley model and PCM, became available at the end of 2003, and these were downscaled to California and analyzed (Hayhoe *et al*., 2004). Of the two models, Hadley is considered a medium climate sensitivity model and PCM a low climate sensitivity model. Both models show sharply different climate impacts for California in more recent versions, relative to previous work.

While the details differ among the models (and depend on the specific emissions scenario being considered), both models now suggest that a sharp increase in summer temperatures in California is a plausible future scenario. Previous versions of these models had shown a warming of about 1–4 °C in the winter by the end of the century, and a similar degree of warming in the summer. The new versions suggest a slightly higher level of warming in the winter (about 2–4.5 °C), but a substantially warming in the summer, amounting to 2.5–4.5 °C under a low emissions scenario (B1) and a dramatic increase of 4.5–9.5 °C under a high emissions scenario (A1). A consequence of the temperature increase is a sharp decline in the

Sierra Nevada snowpack. All of these future changes are subject to the level of uncertainty associated with the CGMs and emissions scenarios used to produce them.

By the beginning of April in a "good" water year, the total amount of water stored in the Sierra snowpack roughly equals the total amount stored in major reservoirs; thus, the snowpack effectively doubles the ability to store water for warm-season uses. By mid-century, the snowpack is projected to decline by about 25–40%. Toward the end of the century, the loss of snowpack could reach 30–70% (4, 300–11, 100 million m^3 of storage) under the low emissions scenario, and a stunning 70–90% (11, 000–13,500 million m^3) under the high emissions scenario (Hayhoe *et al.*, 2004).

It remains to be seen whether the new versions of the other major GCMs will show similar changes when downscaled to California. However, it is clear that climate change has the potential to cause some major disruptions to the California water system, starting within the next two or three decades and continuing over the rest of the century, by which time projections show a doubling of population. Climate change is likely to exacerbate the mismatch in the timing and location of precipitation and to sharpen the competition between off-stream and in-stream water uses. The predicted reduction in the snowpack and the earlier timing of snowmelt will greatly complicate the task of managing California's reservoirs, and make for a more difficult tradeoff between filling reservoirs to capture runoff for warm-season uses versus leaving empty space for flood control in the event of a possible late winter storm. Any future adjustment of the current reservoir operations regime in response to this tradeoff also has implications for meeting ecosystem objectives in the system.

In light of the emerging consensus that climate change will have an impact on California hydrology and the management of the state's hydraulic infrastructure, it seems prudent that water management decision-making processes underway need to factor these changes into supporting analyses. At present this is typically not the case. There are several reasons for the apparent reluctance to consider the potential implications of climate change on water resource systems. But the most basic reason relates to the legal frameworks used for project planning, typically the National Environmental Protection Act or the California Environmental Quality Act. Climate change is not considered in most water resources planning efforts because there is a general perception that significant changes in hydrology will not occur within the typical 20–30 year planning horizon of most NEPA and CEQA studies.

While this conclusion may be legitimate within the legal framework used for project planning, it belies the fact that many of the decisions being made have implications that extend beyond this time horizon. A new reservoir, for example, is typically assigned a useful life of 100 years. Investments made to restore damaged ecosystems seek to assure the viability of key, at-risk species in perpetuity, not just for a few decades. Another reason given for discounting climate change in water resource planning and decision making, is the uncertainly inherent is future climate predictions. While there is recognition that new infrastructure and ecosystem restoration investments must perform over more than 20 to 30 years, the feeling is that future scenarios are difficult to delineate within the limits of the "reasonable and foreseeable" standard used to define future scenarios in NEPA and CEQA studies. As stated previously, the preponderance of analysis seems to be converging on the conclusion that climate change is foreseeable.

Even if change is coming, integrating climate change assessment into water resource decision making processes is hampered by a lack of suitable analytical frameworks for rigorously evaluating the impact of a range of future climate scenarios. In California, most analysis conducted in support of water resource planning responds to the question of how the systems might perform differently should (i) a project be implemented and (ii) the past 70 plus years of hydrology repeats itself in the future. Decision-makers are very used to evaluating

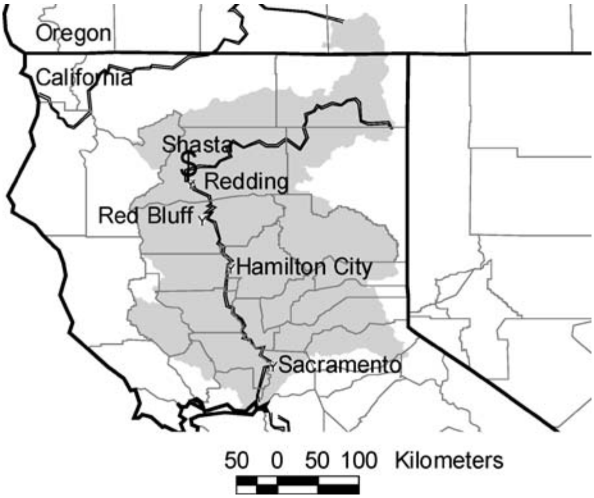

Fig. 1 The Sacramento Valley of California

future projects based on how well they would perform during the 1928–1934, 1976–1978, and 1987–1992 droughts. This reliance on historical hydrology has led to the development of a number of analytical packages that are tightly bound to the historic hydrology and which fail to consider different climate and hydrologic futures.

With the support of the U.S. Environmental Protection Agency, the authors developed an integrated hydrology/water allocation framework for the Sacramento Valley (Figure 1) which apart from being calibrated against historic conditions is unbound from the historic hydrology. While this framework responds to the third challenge, and the emerging consensus about the likelihood of future climate change reduces the uncertainty associated with future climate scenarios, the first reason given for discounting climate change, namely the relatively short planning horizon of most planning studies, remains. After presenting a summary of the integrated hydrology/water allocation framework, this paper identifies specific decision-making processes that are well suited for climate change analysis in the face of this claim and describes the role that the new analytical framework could play in arriving at water management decisions that could be resilient in the face of climate change.

Here it is interesting to note that while the Federal government has not fully embraced the concept that human induced climate change can create major problems in the water sector, the framework described here is gaining traction in California as senior level policy makers are focusing increasing attention of climate change. For example, on June 1, 2005 California Governor Arnold Schwarzenegger signed an executive order stating "that the Secretary of the California Protection Agency shall report to the Governor and the State Legislature by January 2006 and biannually thereafter on the impacts to California of global warming, including impacts to water supply." The current integrated hydrology/water allocation framework will be used as part of this analysis. The executive order also called on California to: by 2010, reduce GHG emissions to 2000 levels; by 2020, reduce GHG emissions to 1990 levels; and by 2050, reduce GHG emissions to 80 percent below 1990 levels.

In spite of this progress, however, actually factoring climate change into water resource planning and decision-making is not universally done. This paper attempts to explain some of the factors that limit this consideration and to provide a method whereby decision-making processes in which such considerations could be successfully implemented can be readily identified.

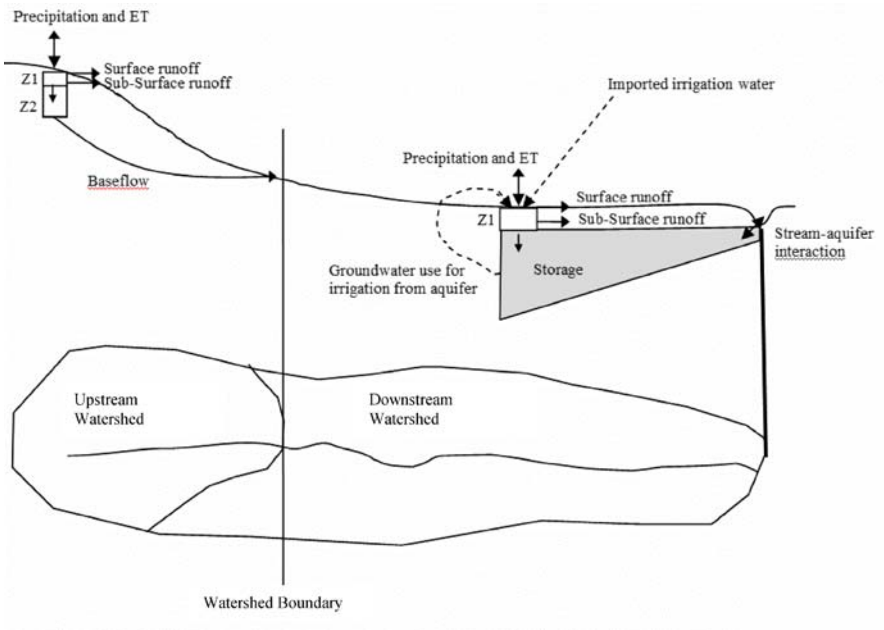

Fig. 2 WEAP conceptual model of upstream and downstream physical watershed processes

The integrated hydrology/water allocation framework

At the most basic level, the integrated hydrology/water allocation framework (Yates *et al.*, 2005a,b), which has been constructed on the Water Evaluation and Planning (WEAP) platform (Raskin, 1992), recognizes that water supply is defined by the amount of precipitation that falls on a watershed. Further, this basic supply is progressively depleted through natural watershed processes, where the watershed itself is the first significant point of depletion through evapotranspiration (Mahmood and Hubbard, 2002). The residual supply, after the satisfaction of evaporative demands throughout the watershed, is the water available to the water management system. Thus, as in the physical realm there is a seamless link in the WEAP framework between climate, land use/land cover conditions, and the management of the water system. This approach also allows for joint management of blue and green water, as described by Falkenmark and Rockström (2004).

Specifically the natural watershed process component of WEAP accounts for two different hydrologic realities (Figure 2). The first is the concept that precipitation in upstream watersheds, with complex topography, steep slopes, and abrupt hills and valleys, contributes to gaining streams with a relatively short time lag (Burness *et al.*, 2004; Eckhardt and Ulbrich, 2003; Winter *et al.*, 1998; and Winter, 2001). Conversely, downstream watersheds with flatter terrain tend to overlie alluvial aquifers linked to river systems to which they can contribute flow and from which they can receive seepage, depending on hydrologic conditions. These groundwater systems also provide storage that can be used to satisfy demands. The WEAP framework also allows for use of surface water supplies imported into a watershed in order to satisfy demand, supplies which are managed by the installed hydraulic infrastructure.

An application of this integrated framework was developed for the Sacramento Valley, which includes three of the primary surface water storage facilities in the California water

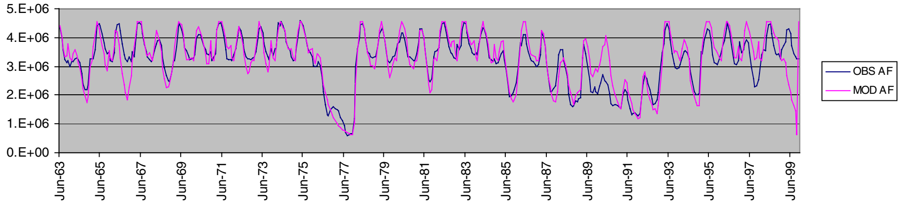

Fig. 3 Observed and modeled end-of-month storage in Lake Shasta

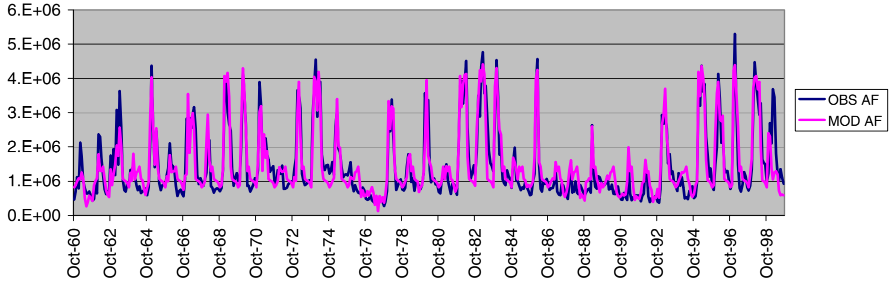

Fig. 4 Observed and modeled monthly Sacramento river flows at freeport

system, Lake Shasta, Lake Oroville and Folsom Lake. The operation of these facilities is based on the assumption that a large portion of the available water supply in the spring months is stored in the higher elevation snow pack. Figures 3 and 4, show the degree to which the calibrated version of the integrated framework was capable of capturing the hydrology and management of the system.

This framework can be applied under future climate change scenarios to investigate how the hydrology could impact associated ecosystem services. Here it is important to point out that there is a great deal of uncertainty associated with future climate scenarios. As such, it would be inappropriate to provide decision makers with a single set of future alternatives. While the Integrated Hydrology/Water Allocation Framework is not automated to generate uncertainty estimates by running an ensemble of future climate scenarios, it can be run in coordination with a tool that can. This is, in fact, an area of ongoing research in California.

An inventory of California water management decision-making processes

Through a series of interviews with informed individuals in the stakeholder community, the authors developed a list of environmental decision making processes currently underway in the California water system that are potentially sensitive to climate change. A sample of ten of those decisions processes are selected to illustrate the range of issues faced by stakeholders and decision makers in the state, as summarized in Table 1. This sample includes decisions ranging from the local to the state, with decision timeframes that are ongoing, on set intervals, or one-time. The impacts of these decisions, while at times viewed in relatively near-term by the decision makers themselves (such as land-use decisions that only consider a 20-year time horizon), are in fact potentially hundreds of years in duration, and longer when extinction of species are considered.

Table 1 3S overview of water management decision processes

	Decision process	Decision summary	Decision timeframe	Impact timeframe
1.	Sacramento river flood control project	State of California is developing a policy related to the financial exposure to flood damage risk.	1–2 years	10–100 + years
2.	Local land use decision-making	Local land use developments must assure that sufficient water supply exists over a 20-year planning horizon.	Ongoing	0–100 + years
3.	Statewide energy planning	California Legislature requires an Energy Policy Report to recommend state policies for current and pressing energy issues.	2 years	2–100 + years
4.	Statewide water planning	The California Water Plan, prepared once every five years, serves as the foundation for local water management decisions.	1–3 years	10–100 + years
5.	Integrated storage investigations	This program is designed to identify promising surface storage opportunities and to quantify both the costs and benefits of new storage projects.	3–5 years	10–100 + years
6.	Ecosystem restoration investments	The Ecosystem Restoration Program (ERP) is tasked to improve habitat and ecological function in the Bay-Delta system and the recovery and support of important at-risk species.	3–5 years	5–100 + years
7.	Yolo bypass shallow water habitat restoration	A consortium will determine if the Yolo Bypass can be operated for improved environmental services without compromising its agricultural water supply function.	1–2 years	5–100 + years
8.	California legislative hearings	The Select Committee on California Water Needs will hold hearings to discuss how federal, state, and local water agencies are planning for climate change.	1–2 years	5–100 + years
9.	Small dam removal (e.g. Battle Creek)	Pacific Gas and Electric, Department of Fish and Game, and community groups will decide whether full or partial dam removal is the most economically and ecologically beneficial approach.	1–2 years	5–100 + years
10.	Hydropower re-licensing (e.g. Yuba, American, and Bear)	Pacific Gas and Electric and community groups will define the most economically and ecologically beneficial strategy for operation of reservoirs.	1–2 years	5–100 + years

In spite of the wide range of decisions, a general observation from these interviews is that few decisions currently being made in the California water arena consider the potential implications of climate change in any formalized manner (with the exception of the legislative hearings which are specifically around climate change considerations). Indeed, in a number of cases the potential impact of climate change is viewed to be too uncertain and too far off to be of much importance relative to the myriad of other factors that influence water management decision-making. In addition, there appears to be a significant disconnect between the water management and the climate change research communities in California. Interviews with climate change researchers typically failed to generate many insights on specific decision-making processes where climate change information was needed, likely because the members of the climate change research community do not actively participate in the decision-making process.

Given the potential impact of climate change, how can better climate change information be introduced into these decision processes? Three criteria were developed to determine what could be the major factors for lack of consideration of climate change in these processes:

- *Sensitivity*: The success or failure of the project could be strongly influenced by climate change;
- *Significance*: The associated potential impacts of climate change are substantial enough to merit a climate change assessment; and
- *Stakeholder support*: Some segment of the stakeholder community has expressed a concern about the potential impact of climate change on the project, thus increasing the chance for climate change to be introduced into the decision-making process.

Together these standards comprise a 3S standard that the authors found useful in assessing the importance of a climate change assessment to a decision making process. Each decision-making process is reviewed against these three criteria, and given a high, medium or low rating, as shown in Table 2. To get a sense of how these criteria are applied, each standard is described for one of the processes.

Starting with the *sensitivity* standard, the Sacramento River Flood Control Project (SRFCP) is in the process of defining a remedy to the financial exposure to flood damage risk that was assigned to the State of California by a recent court decision related to a significant Central Valley flood event in 1986. In this flood, the Linda levee on the Yuba River failed, releasing a 1.2 m high wall into nearby communities. The levee that failed was approximately 80 years old and was constructed by a local entity using mining debris that was piled up without any compaction. It was also aligned on top of porous remnant channels of the Yuba River without constructing a foundation. In the 1920's the Federal and State governments created the SRFCP, which included numerous existing levees, including the Linda levee, often with limited modifications.

After the failure, a group of flood victims sought damages from the State of California, and following 18 years of litigation the court assigned liability for damage caused by the levee failure to the state, even though the levee was constructed by another entity. While the legal justifications for the decision are somewhat arcane, the fact is that the State of California has been exposed to future liability for the failure of many miles of poorly constructed levees that it acquired during the creation of the SRFCP. Policy-makers are now developing a response to this new financial exposure. This decision-making process is given a 'high' sensitivity standard because the flood risk is real and significant based on the magnitude of current flood events, and could increase due to climate change. This process will lead to a plan to indemnify the state against the damage caused by future levee failures could look significantly different

Table 2 3S ranking of decision processes

	Decision process	Sensitivity	Significance	Stakeholder support	Intervention potential
1.	Sacramento river flood control project	High	High	Low	Medium
2.	Local land use decision-making	Medium	Medium	Low	Medium
3.	Statewide energy planning	High	High	Low	Medium
4.	Statewide water planning	High	High	High	High
5.	Integrated storage investigations	High	High	Medium	High
6.	Ecosystem Restoration investments	High	High	Low	Medium
7.	Yolo bypass shallow water habitat restoration	High	High	Low	Medium
8.	California Legislative hearings	High	High	Low	Medium
9.	Small dam removal	High	High	Low	Medium
10.	Water rights permitting	High	High	Low	Medium
11.	Local flood protection Initiative	High	High	Low	Medium
12.	Hydropower re-licensing	High	High	Low	Medium

if climate change were to be factored into the discussion, as damages could be both higher and more frequent.

One of the more challenging determinations in applying the *significance* standard is around the class of local decision making processes leading to the approval of new residential, commercial, industrial and mixed-use real estate developments. Historically land-use decisions in California have been made by cities and counties with the assumption that a local water supplier would expand its service area to include the new development. This changed in 1992 when Contra Costa County approved the residential development project and identified the East Bay Municipal Utility District as the water provider. East Bay MUD objected claiming that is had insufficient supplies to meet projected demand within its existing service area. In response, the California Legislature enacted laws in 1995 (SB 901) and 2002 (SB 610 and SB 221) that sought to build an assurance of sufficient water supply into land-use decision-making in California.

The combined implication of these laws is that cities and counties must include a Water Supply Assessment (WSA) in the documents considered in the approval of real estate development projects. The basic premise is to assure that sufficient water supply exists over a 20-year planning horizon, even in the case of "multiple dry years." While the details of what constitutes an acceptable WSA are being worked out, frequently through litigation, they are being prepared for projects currently under consideration. In reality climate change is probably not a significant factor in the approval of these projects as other planning considerations such as transportation and educational infrastructure dominate the discussion. Further no single project can likely be assigned the responsibility for a potential failure of the statewide water delivery system under a dramatically different climate and hydrologic future. However, the accumulation of these local land use decisions could be affected by climate change. However, this is a discussion better suited to higher level water planning dialogues, such as the statewide water planning described below. Therefore this decision process was ranked medium in terms of significance.

The majority of decision making-processes are ranked low according to the *stakeholder support* standard. Looking at the Statewide Energy Planning process, the Integrated Energy Policy Report is called for on a biennial basis by the California Legislature. The report seeks to: identify historic and current energy trends; forecast and analyze potential future energy developments; and recommend new policies for current and pressing energy issues facing the state. The most recent version was published in 2003 and work is underway to prepare the 2005 edition. One mandated component of the Integrated Energy Policy Report is the Electricity and Natural Gas Assessment Report, which among other objectives seeks to assess trends in electricity and natural gas supply, demand, and wholesale and retail prices for electricity and natural gas and assess the adequacy of electricity and natural gas supplies to meet forecasted demand growth. This study helps to inform generation and demand decisions that could be made within the next two years by analyzing their possible intended and unintended consequences through the coming decade.

While there is a recognition that climate change may have a long-term impact on both the overall demand for electricity and the supply generated by installed hydroelectric capacity, this process is geared towards relatively short-term adjustments in the California energy sector. The stakeholders involved with the preparation of the report have many complex considerations to balance in planning these short-term adjustments which limits potential enthusiasm for climate change assessment. The stakeholders involved with this planning dialogue do not necessarily see the value in adding additional complications to the process.

Each of the ten decision processes had the 3S standard applied. Three examples of decision making processes that ranked highest according to the 3S standard, and are therefore good potential candidates for intervention, are the process of updating the Statewide Water Planning, which is already considering climate change, the Integrated Storage Investigation that has some stakeholder interest in incorporating climate change into the decision process, and Ecosystem Restoration Investments in the Central Valley, which has no stakeholder directly interested in looking into climate change. Each of these processes is presented in further detail, including how the new climate change analytical framework could play a role in improved decision-making, in the following sections.

Statewide water planning

The California Department of Water Resources is mandated by the Legislature to update the California Water Plan (Bulletin 160) once every five years. This document serves as the statewide foundation upon which a myriad of local water management decisions are made (Significance). The last update was published in 1998 and the next edition was scheduled for release in 2003. To date, it has not been released due to the fact that the approach taken in developing the document has undergone major reform since Bulletin 160–98 was published. Historically, the approach to develop projections of future demand and to compare these to the yield provided by currently installed water infrastructure under average and dry conditions (Sensitivity). The analysis typically lead to an assessment of how much additional supply development was required to meet anticipated demand. Further, Bulletin 160 was historically developed by DWR staff with only limited input from the public.

This has changed with Bulletin 160–2003, which has adopted a new portfolio approach to water planning which has its origins in financial planning. Much like an investor would analyze the potential value of a financial portfolio by making different assumptions about the performance of individual assets, the new Bulletin 160 will consider the future, and by nature uncertain, role that a range of factors will play in determining "future" balances between water supply and demand in California. DWR has been guided in this transformation by an advisory panel comprised of over 70 stakeholders. For the first time, one of the potential factors that may influence these futures, climate change, has been recognized and considered (Stakeholder support).

According to information released by the Department of Water Resource, in addressing global climate change in the current update of Bulletin 160, rather than focus on causes of global climate change, the update will look at the potential impacts of climate change on water resources in California and potential strategies for adapting to these changes. The word commonly used to describe this approach is "qualitative." The department suggests, however, that future updates of the Water Plan will contain more intensive evaluations of climate change as more data become available, modeling techniques are improved, and management strategies implemented. The intention is to develop a more quantitative assessment of climate change in future editions of Bulletin 160.

The qualitative assessment of climate change in the current version of the Bulletin 160 will be contained primarily in a two papers included in a chapter on climate change in the document referred to as the Reference Guide. The first of these papers is a survey of the literature documenting the current understanding of global climate change and its potential impact on California. The second paper is a compilation of data for California that attempts to describe the extent to which the climate shifts may already be underway and to lay out important markers that can be used to monitor future changes in climate and hydrology. The decision was made, however, not to include climate scenarios in the analysis of various future portfolios included in this edition of the document, but instead, to spend some time evaluating various analytical platforms for potentially including this analysis in the next version of the document.

The DWR staff responsible for selecting an analytical platform for future analysis is considering the integrated hydrology/allocation climate change assessment tool developed by the authors and understands its unique integration of watershed response and water management. With a next phase of support from the U.S. Environmental Protection Agency (EPA) the authors will inform the decision regarding the ultimate selection of a model by developing a study on water management tradeoffs associated with future climate change. This will be accomplished by running the tool under a variety of climate scenarios and priority/preference landscapes and the development of a matrix of tradeoffs. The results of these analyses will then be provided to DWR decision makers. Ongoing meetings between the authors and DWR staff are guiding the formulation of the climate change scenarios that will be investigated using the integrated framework.

Integrated storage investigations

The CALFED Bay-Delta Program is an initiative of several federal and state agencies designed to develop and implement a plan to better balance the off-stream and in-stream uses of water in California. As part of the CALFED Record of Decision published in 1999, a commitment was made to launch the Integrated Storage Investigation (ISI). This program is designed to identify promising surface storage opportunities and to quantify what stand to be both the substantial costs and benefits of new storage projects (Significance). Storage programs are part of the CALFED water management strategy that combines storage with program actions such as conservation, water transfers, and habitat restoration. Together these complementary actions will contribute to meeting CALFED's water supply reliability, water quality, and ecosystem restoration objectives. The analytical test of performance typically applied in this assessment is how CALFED actions will perform during the dry periods that characterize California hydrology (Sensitivity).

Since its inception, the ISI has successively narrowed the field of candidate surface storage projects to a current list of five projects. These include:

- Raise Shasta Dam on the Sacramento River
- Construct an off-stream reservoir in the Sacramento Valley
- Construct an in-Delta storage facility by converting a Delta island to a reservoir
- Construct an off-stream reservoir in the San Joaquin Valley
- Raise or Replace Friant Dam on the San Joaquin River

Studies are currently being conducted to assess the viability of each of these projects with goal of developing draft environmental documentation by the end of 2006.

The potential off-stream storage facility in the Sacramento Valley is located in the sparsely populated valley in the Coast Range Mountains. The name of the single community in the valley, Sites, is used to describe the Sites Reservoir project. This facility, which could have a capacity of up to 2,500 million m^3, will be operated by diverting water from the Sacramento River. Water will be returned to the system from storage either by delivering it to water users on the west side of the Sacramento River in exchange for their normal Sacramento River diversions or through the construction of new conveyance works from the propose reservoir back to the Sacramento River. One issue of concern is the impact that the potential diversions and returns will have on the flow regime in the Sacramento River and on the important in-stream benefits supported by this flow regime. A group of stakeholders has spent over two years designing a required flow regime that could be used to guide the operation of Sites Reservoir. This group recognizes that climate change could significantly impact the components of this flow regime (Stakeholder support), but to date has not had the ability to bring climate change directly into the process.

The benefits associated with a major water storage project such as Sites Reservoir will depend on the characteristics of future climatic and hydrologic regimes. Using the next phase of support from the U.S. EPA the authors will use the integrated hydrology/allocation climate change assessment framework to simulate the operation of Sites Reservoir under a variety of climate future climate scenarios. The results of this analysis will be provided to interested stakeholders in the context of the larger decision-making process. As the authors are actively involved with the applications of analytical tools less suited for climate change assessment to the analysis of the Sites Reservoir storage option, this will allow for useful benchmarking of the integrated framework against other models in current usage in California. In modeling rich environments such as California this technical benchmarking is a critical step in generating support for climate change analysis.

Ecosystem restoration investments

The Ecosystem Restoration Program (ERP) of the California Bay-Delta Authority (formally CALFED) has been created to meet several important objectives. These can be summarized as improving habitat and ecological function in the Bay-Delta system and the recovery and support of important at-risk species. Since its inception seven years ago the ERP has invested tens of millions of dollars (Significance) in a variety of ecosystem restoration projects designed to help assure regulatory compliance for other aspects of the CALFED program, such as water supply and flood control. These projects fall into six broad categories related to the ERP goals that include at-risk species, ecological processes, harverstable species, habitat restoration, non-native invasive species, and environmental water and sediment quality. One critical issue in assessing the utility of these investments is whether over the decades-long time scale anticipated for the realization of a return on ecosystem restoration investment, climate change will have an impact on the design and ultimate success of a particular investment (Sensitivity).

The Yuba River offers an excellent example of this issue. The Yuba drains a watershed of approximately 3,500 square kilometers from the crest of the Sierra Nevada to the confluence of the Feather River near Marysville and Yuba City in the northern Central Valley. The north fork of the Yuba River flows into Bullards Bar Reservoir above the confluence of the north and middle forks. Further downstream, the middle and south forks of the Yuba River flow into Englebright Lake, which provides water-based recreational benefits; 55 million m^3 of stored water-right capacity; and hydroelectric generation to meet the annual energy needs for 50,000 homes. The height of Englebright Dam effectively blocks fish migration although biological data suggests that the Yuba River above Englebright historically had habitat that supported anadromous fish species. The Upper Yuba River may present an opportunity to improve habitat for native anadromous fish species whose populations are in decline, while developing a comprehensive plan that will restore ecological health, improve water management and provide positive benefits to the public.

In 1998, the ERP recommended a studies program to determine if returning steelhead trout and spring-run salmon to the Yuba River was feasible by changing Englebright Dam. Through active public involvement and collaborative efforts, stakeholders agreed on key issues and concerns to be addressed in the studies, including upstream and downstream habitat, water quality, sediment, flood risk management, water supply and hydropower, and economics. Study plans were developed for each issue and consultants were engaged to implement the plans. The implication is that if the studies reveal that the restoration of anadromous fish to the Upper Yuba is feasible, then additional funds will be invested to make the necessary structural and operational changes in the system.

As the Yuba River is a classic snowmelt driven Sierra Nevada watershed, there is a strong possibility that climate change will have an influence on the hydrologic conditions in the basin, and that these conditions may have a bearing on the viability of any proposed anadromous fish recovery strategy. Under the second phase of support from the U.S. EPA the authors will refine the current formulation of the Yuba River watershed in the hydrology/allocation climate change assessment tool and add climate change considerations to the ERP analysis. This information will be provided to stakeholders in the hope of introducing climate change into the process. Stakeholders interested in climate change will collaborate with the authors in developing the refined model representation of the Yuba River system and in the definition of future climate and watershed management scenarios.

Conclusions

Future climate change has the potential to substantially alter the hydrologic regime within which water management in California takes place. This nesting of water management within a hydrologic regime motivated the development of the integrated hydrology/water allocation climate change assessment framework embedded in WEAP. This tool has been unbound from past hydrology and is driven solely by the climate signal that will evolve over the course of the coming century. It is uniquely suited to introducing climate change assessment into water management decision-making processes and an understanding of tradeoffs.

Not all water management decision-making processes, however, are necessarily amenable to the introduction of a climate change impact assessment at this time, as awareness of the importance of climate change generally remains low. The authors have developed and applied the 3S standard which weights the Sensitivity of the project under consideration to climate and hydrologic variability, the Significance of the project in terms of the contemplated investment, and the degree of Stakeholder support for a climate change impact assessment. While numerous decision-making processes fail to rank high on all of the 3S thresholds, three have been identified where the application of the integrated hydrology/water allocation framework is warranted: statewide water planning; the integrated storage investigation; and ecosystem restoration investments. These three processes have expressed varying degrees of interest in including climate change analyses into their processes, with the Statewide Water Planning having the most, and the Ecosystem Restoration Investments having the least level of interest. Future support from the U.S. EPA will be used to conduct climate change impact analyses in support of these planning dialogues. By working to introduce climate change analyses into these processes, we can learn about barriers to inclusion of climate change research more broadly.

Introducing climate change into decision-making processes represents both a challenge and an opportunity. The challenge is to convince decision-makers for water policy that it is in their interest to consider climate change in their decisions, although they are still not entirely convinced is needed. The opportunity is to begin to move climate change research from the academic to the public policy arena – one that is taken on directly in the approach presented here. It is heartening, that at the highest level of state government, there in an increasing interest in better understanding the potential impact of climate change. What is needed, however, is more than just high level assessments. Instead, each individual water management decision should consider the potential impact of climate change. The use of the integrated framework as part of the collaborations described in this paper is a first step in implementing this recommendation.

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