COMPELLING ADAPTIVE WATER MANAGEMENT TO MEET THE IMPACTS OF CLIMATE CHANGE

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A. Abstract

Global water consumption doubles every twenty years, twice the population rate. Against this back drop, the leading issue facing the water field is how to utilize effective adaptive water management ("AWM") techniques to plan and develop adequate water supplies to address the impacts of climate change. Water planning and development historically developed out of rigid supply/demand engineering. This one dimensional approach has institutional flaws which restrict effective problem solving. Climate change, population growth and competition for water supplies between food production, energy generation and human needs compels an interdisciplinary approach to AWM that focuses effective tools in the land use, legal and engineering arenas to address water planning and management. This paper identifies adaptive management variables in an interdisciplinary approach to meeting the challenges of climate change on water supplies.

B. Key Words

Adaptive, Interdisciplinary, Climate

C. Introduction

During the 20th century, the world's population tripled while the use of renewable water resources grew six-fold. As these population and water consumption growth rates continue into the 21st century, and as industrialization and urbanization persist, global water stress will keep intensifying. *See* World Water Council (2010). The imbalance between water use and water resources will affect global food security, since an average 66% of all water withdrawals are used for irrigation and the production of food for human consumption (up to 90% in arid regions). *Id.* Water stress will also impact energy production. Both hydropower generation and thermal energy production consume great amounts of water. Brekke et al. (2009).

All of these issues may further be compounded by changes in the earth's climate. The Intergovernmental Panel on Climate Change has provided some estimates of how climate may change in the next several decades. Pachauri and Reisinger (2007). (higher air temperatures, decreased snow packs, rising sea levels, increased flood peaks, more variable climate patterns, etc.). However, we currently have only a tertiary understanding of the process driving these changes, the sequence of the changes, and the manifestation of these changes on differing global and regional scales. We do know that because climate changes will probably affect fundamental drivers of the hydrological cycle, they could have a significant impact on the world's water resources. Brekke et al. (2009).

Water resource managers will therefore need flexible and interdisciplinary strategies to develop and plan for water resources in the face of the unknown implications and scales of climate change *Id.* Adaptive water management has been widely touted as an approach that can tackle such uncertainties and complexities. AWM stresses increasing and sustaining the capacity to learn while managing through an iterative process of testing and improving methods of analysis and management policies and practices in response to insights from monitoring outcomes of implemented management strategies. Medema and Jeffrey (2005).

The purpose of this paper is to identify key interdisciplinary variables that water resource managers should consider in their AWM practices. It presents an approach that practitioners can use to manage these variables to effectively plan and develop water supplies with enough flexibility to address unknown contingencies of climate change. Sections D and E of the paper discuss the history and modern elements of AWM. Section F indentifies and defines the key AWM interdisciplinary variables and presents the Water Availability Adaptive Management ("WAAM") approach to water planning, use and development. In Section G, WAAM is applied to a realistic hypothetical watershed to demonstrate how managing the key variables can help solve current water dilemmas and plan for future water needs. The conclusion recommends that water resource managers begin and continue to transition to adaptable AWM and WAAM-like practices immediately to cope with climate change and stave-off major water dilemmas.

D. History of Adaptive Water Management

AWM is defined by New Approaches to Adaptive Water Management under Uncertainty ("NeWater"), a research project supported by the European Commission to study and foster AWM, as a "an approach that addresses uncertainty and complexity by increasing and sustaining the capacity to learn while managing." AWM arose out of decades of experiments to make ecosystem management more flexible and systemic. Medema and Jeffrey, (2005). Traditional approaches to natural resource management assume that social, economic and environmental factors and issues are predictable. AWM, on the other hand, recognizes that these factors are not always predictable due to environmental and demographic variability, human sampling and measurement errors, and incomplete understanding of ecosystem complexity. AWM is thus grounded in the general belief that to properly manage natural resources, it is critical to not only understand the natural world but the ecosystem as a whole – including the influence and affect of human activities on and behavior towards the system. Constanza et al. (1993); Prato (2003).

The concept of AWM more than likely originated in the 1970s at the international Institute for Applied Systems Analysis in Vienna, Austria, with its origin in the field of decision analysis. The decision analysis framework can support the evaluation of complex natural resources management systems by emphasizing the necessity of explicitly stating management objectives (including those in conflict), designing and evaluating creative alternatives, explicitly addressing uncertainty, and incorporating stakeholder values. Ohlson 1999); Walters (1986). AWM also borrows from the field of social learning. Social learning is the "building of knowledge within groups, organizations, or societies." It is based on the view that the following elements are necessary to change social behaviors and conditions: critical self-reflection; participatory, multi-scale, democratic processes, individual and social reflection; and social movements that can improve political and economic conditions. Gunderson et al. (1995); Goodin (1996); Pahl-Wostl, C (2002).

Today, AWM is generally viewed as a management process that is both anticipatory and adaptive. Hypothesis and assumptions are developed based on a thorough understanding of an ecosystem to anticipate possibilities and uncertainties that may impact the system. These hypothesis and assumptions are then translated into plans and actions. The plans and actions are evaluated and monitored in order to test their affect on the system. Finally, the hypothesis and assumptions are adapted according to the test results to improve the overall management framework. The process is regularly repeated to guarantee continuous improvement. Medema and Jeffrey (2005). AWM is widely advocated as the paradigm which natural resource managers should adopt. Its advocates build on the recognition that ecosystems are complex, adaptive and self-organizing, and that management systems must be able to readjust to change or surprise in the system. Gunderson and Holling (2001); Pahl-Wostl (2002). AWM helps achieve these goals because its management interventions are developed carefully through monitoring programs that evaluate outcomes on a continual basis. This allows awareness of ecosystem functioning increase and management to proceed, even in the face of lack of sound scientific foundation for action. Medema and Jeffrey (2005).

E. Current AWM Approaches

AWM is still an evolving theory. As a result, the AWM concept, by definition, is not well defined and constantly changing. Many planners and disciplines have differing descriptions for and understandings of the practice. Goodin (1996); Pahl-Wostl (2002). This lack of clarity is exasperated by the very nature of AWM. AWM is predicated on uncertainty and learning, with an emphasis on a *lack* of procedure so that ecosystem policies can be changed and improved with flexibility and adaptability. Medema and Jeffrey (2005). The only three steps that AWM is generally believed to clearly include are: 1) development of management experiments; 2) gathering information for and increasing understanding of uncertainties; and 3) development of continuous monitoring procedures and space for adjustments. Walters (1997); Gleick (2003). The following are some of the current (and non-exclusive) variations in AWM approaches:

- **Passive AM:** This approach formulates predictive models of ecosystem responses to management actions, bases management decisions on model predictions, and uses monitoring data to revise model parameters. It is non-experimental, which makes it rather simple and inexpensive to implement. However, some believe that it lacks statistical validity and does not provide reliable information for decision making. Medema and Jeffrey (2005).

- **Active AM:** Experimentation is a key element of this approach. Active AM uses experiments that replicate and randomize management actions in the development and evaluation of management decisions. The experiments results help verify whether a particular management action has achieved a desired outcome. This approach is generally believed to yield reliable information about how management actions influence socioeconomic and ecological conditions. *Id.*

- **Policy-oriented AM:** This approach recognizes that AWM takes place in the context of complex political processes where organizations cooperate and function based on established rules and clearly defined roles and responsibilities. It emphasizes the inclusion of negotiation, planning, and structured stakeholder participation processes in decision-making. Lee (1999).

- **Adaptive Environmental Assessment and Management ("AEAM"):** AEAM advocates for managing ecosystems on larger spatial scales and over longer time frames. It emphasizes balancing multiple management objectives and views in a collaborative decision-making framework that embraces uncertainty. Walters (1986); Gunderson et al. (1995); Gunderson and Holling (2001).

- **Adaptive Management Cycle:** NOAA has established an AWM learning cycle with the following sequence of continually repeated steps: 1) establish a stakeholder team; 2) define the problems; 3) establish goals; 4)specify a conceptual model that expresses how the system in question functions, highlighting uncertainties and acknowledging outside factors; 5) develop hypotheses about the effects of different management actions that address the uncertainties; 6) design experiments/interventions to test hypotheses; 7) design a monitoring plan to measure the impacts of the experiments; 8) implement experiments; 9) monitor; 10) evaluate results; and 11) reassess and adjust the problem statement, goals, conceptual model, experiments and monitoring plan. Medema and Jeffrey (2005) (taken from National Oceanic and Atmospheric Administration Coastal Services Center).

- **"Soft-system" AM:** This approach purposefully avoids development of ridged generic procedures in the belief that flexibility and adaptability are key aspects of AWM. It shuns top-down control in favor of an open, participatory and recursive process to formulate policy and select indicators. It uses systems analysis and conceptual qualitative modeling rather than rather than technical analysis and formal quantitative modeling. The drawback to "soft-system" AM is that it can be hard to report and/or demonstrate to auditing authorities. *Id.*

While these approaches are each effective in their own way, the input variables often employed in water management are often incomplete or hastily developed in response to need. An effective adaptive management method requires that available or known variables be identified, weighted and supplemented periodically to be responsive to changing conditions. Moreover, the variables, or tools, to respond to changing conditions are science based, cultural, economic, legislative and political – e.g., multidisciplinary in nature.

F. Application of Interdisciplinary Adaptive Management Methods to Climate Change

The management of variables that impact water planning, use and development is interdisciplinary. To view water management strictly as a science or engineering exercise is to overlook the cultural, legal and economic forces that drive the use and supply of water. Reciprocally, an approach that views water management as a political process ignores economics, demographics, and institutional driven considerations. Effective water management recognizes the existence of all supply and demand side variables. Pahl-Wostl et al. (2007).

While some variables “cross-over” between institutional, physical and elective-political-cultural variables (i.e., population can be considered political/cultural as being encouraged/discouraged by elective incentives or discentives), the variables that impact water supply and demand largely fall into three columns:

WATER MANAGEMENT VARIABLE CHART

INSTITUTIONAL VARIABLES	PHYSICAL VARIABLES	ELECTIVE, POLITICAL & CULTURAL VARIABLES
Water Law in the Jurisdiction	Geology	Utility Practices
Water Rights in the Jurisdiction	Climate Patterns/Characteristics	Water Provider Service Areas/Cooperation
Water Quality Laws	Population	Waste Water Provider Service Areas/Cooperation
Administrative Practices	Energy-Water Nexus	Land Use Patterns
Tribal-Indigenous Claims	Food-Water Nexus	Politics & Economics of Growth
Transboundary Compacts/Treaties	Wetland-Riparian Zones	Conjunctive Use and/or Water Banking
Acquisition of Existing Rights	Surface Water Availability	Surface Water Storage
	Ground Water Availability	Industrial/Commercial Base
		Instream & Environmental Flows
		Species & Habitat Preservation
		Cultural Considerations
		Flood Management
		Conservation
		Pollution
		Waste water treatment methods

A summary and brief definition of the interdisciplinary variables is as follows:

I. INSTITUTIONAL VARIABLES:

Water Law in the Jurisdiction: The laws which govern the acquisition, use and rights to water influence decision making. For example, American prior appropriation law (employed in most of the western United States) accords a property right to a certain quantity of water as long as the diversion, transport and application of such water is without waste. In the event of a reduction in supply, the seniority of a right takes water and more recent users are curtailed (“first in time, first in right”), without preferences of use. The English riparian law (employed in the eastern United States as well) accords a “reasonable share” of the waters of a stream, with each party sharing in reduction if water supplies are reduced, with preferences given to certain classes of uses.

Water Rights in the Jurisdiction: Pre-existing entitlements to divert, store or otherwise use water, and their geographical points upon a watercourse, often dictate the response required to meet shortages of supply. In many jurisdictions, established rights owned by third parties must be protected by any action taken to meet the impacts of climate change.

Water Quality Laws: Many jurisdictions tie the level of water treatment to the capacity of the receiving stream to accept levels of pollution while maintaining certain ambient water standards. Thus, reductions in water flow reduce discharges or increase levels of required treatment.

Administrative Practices: Administrative enforcement and practices (based on regulations, policies and sometimes merely custom) often have greater influence over water uses than the legislative or judicial framework. An example of an administrative practice is the discretionary allowance of the doctrine of waste. In most jurisdictions the diversion of water without a beneficial use or diverting too much water for a particular use is prohibited; the determination of what is reasonable or wasteful is often an administrative practice.

Tribal-Indigenous Claims: Displaced cultures, such as the Native American Indians of the United States or the Aborigines of Australia have rights to water under various theories recognized by legislative acts or judicial decisions. These rights or claims typically presume a quantity of water to accomplish the purposes of the tribal culture or homestead, and often take priority over more recent uses.
In the United States, the claims differ by tribal heritage with hunter-fisher tribes being entitled to a certain free flow of a watercourse and other agrarian tribes' rights being quantified on the basis of an amount of water necessary for irrigated crop production.

Transboundary Compacts/Treaties: Shared watercourses are often the subject of treaties or compacts to avoid armed or judicial conflict over waters. These agreements are seldom flexible to accommodate changing demographics or changes in water availability as a result of climate change. Two examples illustrate this point: 1) The Colorado River traverses seven states in the United States plus the country of Mexico. In 1922, using then available records of stream flows, the river was "divided" to require a bypass of a specific quantity of water that was presumed to be 50% of the flow to the lower basin states plus the treaty entitlement to Mexico. Unfortunately, history has proven the flow of the river to be less than projected and the impact of climate change could further exacerbate this error.

Acquisition of Existing Water Rights: Market dynamics often compel (and allow for) the acquisition of existing entitlements to water to be leased, borrowed, exchanged or purchased to satisfy demands with higher values. This approach to satisfying demand has been very successful in jurisdictions employing the prior appropriation doctrine for water rights.

II. PHYSICAL VARIABLES:

Geology: The geology of a watershed directly impacts groundwater storage and recharge, surface water storage, movement of water and the interconnection between surface and groundwater. This variable is a constant once determined for a basin.

Climate Patterns/Characteristics: Climate dictates the amount, timing and manner in which precipitation, evaporation, crop transpiration, and thermoelectric generation for heating and cooling occurs.

Population: Population growth and migration impacts human water needs, food and energy production requirements and social growth.

Energy-Water Nexus: A term given to the relationship between the amounts of water required for energy production, inclusive of harvesting raw materials, transport and generation of energy. An example of this variable would be a mandate to increase ethanol based hydrocarbons and the impact of such a policy by virtue of the water required to grow crops, transport crops and produce and distribute ethanol from corn.

Food-Water Nexus: A term given_to the relationship between the amounts of water required for the production of food, inclusive of growing, harvesting and processing of food materials and their transport to markets.

Wetland-Riparian Zones: The location, extent and biological values of wetland and riparian zones greatly impacts the availability, quality and movement of water and pollution transport. Increasingly, the value and creation of healthy riparian zones is being fostered to increase water values.

Surface Water Availability: The availability of surface water is tied directly to climate patterns and characteristics, such as watershed yields and precipitation characteristics (snow, rain, etc). Water availability is then a site specific determination based on local laws that allow permits to divert, store or use water without interference with other permits or values.

Ground Water Availability: The availability of ground water is tied directly to climate patterns and characteristics, as well as geology. Physically, the availability of water in storage or moving beneath the ground can be assessed as being tributary to (connected with) surface water or sufficiently disconnected in space or time as to be considered non-tributary to a surface watercourse and distinctly held in storage. The amount of water recoverable then is dependent upon practices and the legal framework employed in the jurisdiction that defines title or impact to other surface or groundwater users. Changing the legal criteria will change the amount of water available as a variable.

III. ELECTIVE, POLITICAL & CULTURAL VARIABLES:

Utility Practices: Legislative, custom and habit of utility management impacts water development and use. Examples include utility billing schedules which incentivize conservation and high efficiency plumbing standards.

Water Provider Service Areas/Cooperation: The geographical service area of providers of water, their competition for available supplies and the degree to which they cooperate to maximize a shared resource all directly impact the amount and pattern of water use and return flows of water after use.

Waste Water Provider Service Areas/Cooperation: The geographical service area of waste water treatment providers, their methods of treatment, the location of discharges and the degree to which they cooperate all impact the amount and patter of water use, water quality and return flows of water after use.

Land Use Patterns: The location, type, land use mix, topographical site plan and density of growth patterns influence the location and extent of water, waste water, and storm water patterns and usage.

Politics & Economics of Growth: Incentivizing, directing or restricting growth carry political and economic consequences. The extent to which growth is controlled influences not only water and waste water patterns but economic functions which finance other variables such as pollution control.

Conjunctive Use and/or Water Banking: A term used to describe the combined use of surface and ground water. Typically, this involves managing an aquifer by depositing available surface water into groundwater storage during wet years for later removal. Water Banking need not involve ground water storage and may serve as an effective marketing and accounting tool.

Surface Water Storage: A term used to describe the impoundment of water for later beneficial use.

Industrial/Commercial Base: While potable water for human consumption is fairly uniform and can be predicted on a per capita basis, the mix and nature of water for commercial and industrial use varies greatly by the nature of the industry or commercial use. Understanding, incentivizing or restricting certain types of commercial or industrial uses can result in water conservation.

Instream & Environmental Flows: Terms used to describe the amount of water determined to be needed to maintain an environmental, recreational, or aquatic goal. Reduction in water flow can impair species, hamper waste water assimilation and increase sedimentation and erosion.

Species & Habitat Preservation: Closely related to instream and environmental flows is water set aside for the maintenance, enhancement, or habitat of a species deemed sufficiently important to preserve. Water set aside for this use can be substantial as in the case of North American salmon fisheries and spawning habitat.

Cultural Considerations: History of an area often dictates the use of water for purposes deemed important for preservation of ways of life. Examples range from water set aside for aesthetic experiences in recreational-tourist economies to prohibitions upon the placement of dams on free flowing rivers historically valued for their pristine condition. In other instances, religious, cultural or historical views as to water use impact water use decisions.

Flood Management: Flood management techniques modify historic water flows, aquifer recharge and population-development patterns.

Conservation: A term used to describe technologies or practices which result in a beneficial reduction in the usage of water.

Pollution: A term used to describe the contamination of water bodies by discharge or accretion of harmful matter. Typical forms of pollution include industrial and municipal discharges and livestock and fertilizer run-off.

Waste Water Treatment Methods: The method and technology for treatment of waste water impacts water availability. Different treatment methodologies result in differing degrees of water consumption and differing levels of water treatment, all impacting quality and quantity of water availability in a watershed.

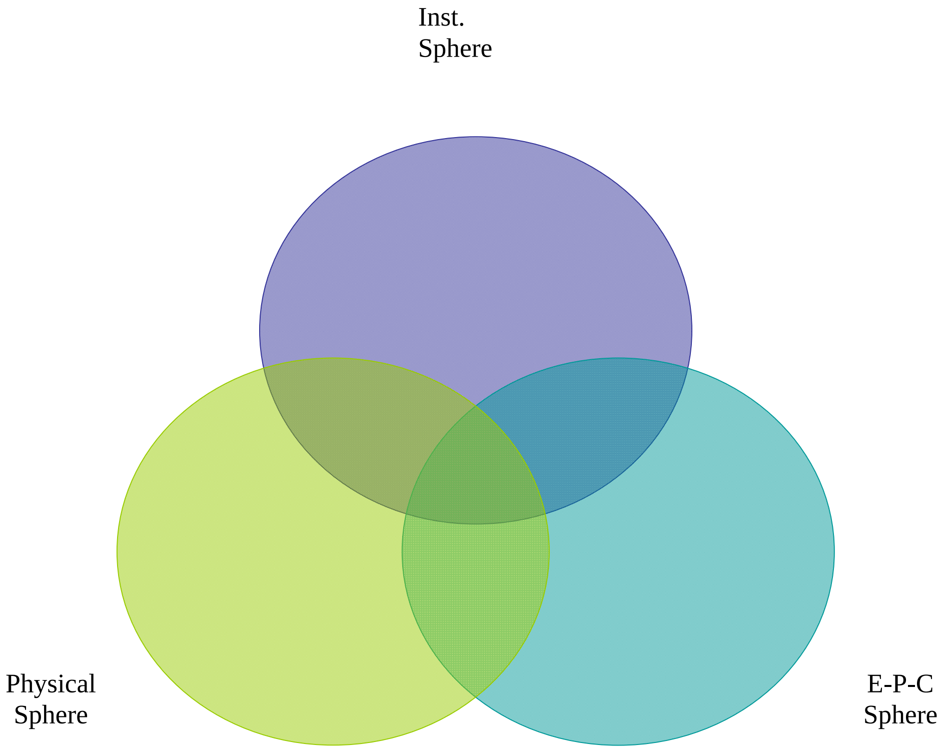
The two “elephants in the room” are population and climate change. In the last fifty years, the world population has more than doubled. Water use has out-paced population as developing nations decrease the per-capita gap between developed nations and undeveloped nations. Water demands for food and energy production rise exponentially with population growth. *See* World Water Council (2010).

But for the impact of climate change, water planning historically assessed available supplies using watershed modeling and historical run-off records (for surface water) and geo-hydrological models for determining recoverable groundwater. California Department of Water Resources (2008). However, with climate change comes uncertainty in calculating and projecting future supply side water availability. Pahl-Wostl et al. (2009). Climate change predictions (and that is all that anyone can say they are), indicate a wide variability in projected impacts. In some regions, warmer and wetter conditions may prevail. In other regions, warmer and dryer conditions are anticipated and still in other areas, wetter and colder seasons are projected. California Department of Water Resources (2008) (predicting drought in southern California and flooding in the Sierra Nevada Watershed). In areas of the western United States, where the population growth of America has largely been centered, precipitation that once occurred largely in the winter season as snow may now come at different times of the year or at higher temperatures. This, in turn, may result in more precipitation coming as rain rather than snow, with a corresponding reduction in managed snowpack conditions. Application and evapotranspirative rates for crop production and lawn irrigation are almost certain to be altered. California Department of Water Resources (2006); Colorado Water Conservation Board (2008).

With the supply side of the water management equation in flux, a greater awareness on management of demand side variables is predicted. Institutional constants such as the jurisdiction’s laws relating to water use and water quality laws, once thought inflexible now find sufficient pressure for change to more flexible criteria. Pahl-Wostl et al. (2009). For example, fallowing crop agreements now result in loans of agricultural water during times of drought to thirsty industrial and municipal users. *See* the Colorado water right loan statute, CRS, 37-83-105; *and see*, Tarlock et al. (2002) (In northern California, during the summer of 1988, the East Bay Municipal Utility District offered irrigators a dry year option based on a payment for the water of $50 per acre-foot). In other instances, municipal water quality treatment in some jurisdictions encourages land application of treated effluent for large irrigation uses over direct discharges. *See* California Partnership for the San Joaquin Valley (2009) (The California Partnership for the San Joaquin Valley’s March 2009 Strategic Action Proposal recommendations for water supply, quality and reliability include augmenting recycled water projects).

An interdisciplinary (i.e. legal, land planning, and engineering-sciences) approach to the variables that impact water availability and demand is the preferred management model for adapting to changing patterns, effecting legislative and political change and accommodating fluctuations in the water supply-demand impact of specific variables. Medema and Jeffrey (2005). Employing an adaptive Venn Diagram model using the Water Management Variable Chart set forth above is a useful adaptive management tool. The Institutional Variables are represented by the “Inst. Sphere”, the Physical Variables are represented by the “Physical Sphere”, and the Elective-Political and Cultural Variables are represented by the “E-P-C Sphere”. Whenever one or more variables in a sphere takes greater significance or importance, that sphere is assumed to encroach upon the other spheres. The variables within those spheres must then adapt by changing, eliminating, conforming or modifying to create a projected balance between supply and demand. This approach can be labeled as a Water Availability Adaptive Management approach (“WAAM”). Water availability is the driver, as influenced by climate change. Substantial changes to the patters, timing and amounts of water available to meet demands triggers reaction and adaption by changing the demand side variables.

WATER AVAILABILITY ADAPTIVE MANAGEMENT VENN DIAGRAM



As water availability is influenced by the impacts of climate change, competing variables correspondingly must adapt and give way to yield greater efficiencies. Otherwise, trade-offs must be made between these variables. A flexible periodic reassessment of the value or weight to be given to the variables will allow a finite water resource to be managed in a way that meets the jurisdiction’s goals, as they exist from time to time. Climate change is a relatively slow-influencing element on water availability. In jurisdictions that do employ comprehensive water planning, it is typically performed at 10 to 30 year intervals (re-assessments or updates). This frequency is adequate to react effectively to any impact that climate change may have on a watershed. Jurisdictions which do not employ interval based updates to water planning are well advised to adopt such AWM.

G. Application & Findings

I. <u>HYPOTHETICAL</u>:

A theoretical example is employed in a relatively small watershed stretching 100 miles to its confluence with the sea. At the top of the watershed are low mountains of 2,000 meters that have historically seen snowpack accumulations of 3.0 meters in depth down to an elevation of 1,000 meters above sea level. The principal economies are grain and cattle operations in the lower plains. Precipitation at these elevations averages 0.20 meter/year, and for this reason, crops are irrigated during the growing season of April 1-October 1. Two cities are located in the watershed: one with a population of 5,000 persons is located 50 kilometers above the confluence of the river; and the second larger city with a population of 25,000 is located on a terrace 10 kilometers from the confluence or mouth of the watershed.

Ranching and the agrarian nature of the watershed are culturally important to the watershed's inhabitants. In addition, a new eco-tourism economy has taken hold in the watershed, particularly in the mountainous region. The primary economy of the smaller city (and most small towns) is agrarian and tourism. The primary economy of the larger city is service industry, a refinery of oil produced from a neighboring watershed, and a seaport that handles refined oil for shipping abroad. Both cities have their own respective water diversion, treatment and waste water collection and treatment facilities.

The watershed is presently adequate to accommodate existing industries and population. Nevertheless, any new demands are anticipated to affect stream flows in the lower portions of the watershed. A recent proposal has been made to site a silicone chip manufacturing company in the larger city. This proposal promises to bring up to 3,000 new high-paying jobs. Correspondingly, it is anticipated that up to 8,000 new residents will move to the larger city. Ancillary services and commercial growth as a result of this influx of new residents is expected to bring an additional 3,000 persons to the larger city. The estimated schedule for this to occur is five years from the date of approval.

II. HYPOTHETICAL IMPACT OF CLIMATE CHANGE

A new study has shown that in the next 25 years, it is expected that climate change will result in a rising of the snowpack level from 2,000 meters to 2,500 meters, and the growing season is expected to increase by up to two weeks in duration. Precipitation is not expected to materially change but daytime summer temperatures are expected to rise from an average high of 78°F (26°C) to 80°F (27°C).

These events are expected to result in demand outstripping available supply in all but the spring run-off season, with a corresponding loss in tourism and shortages to water users.

- If the watershed employs the correlative rights doctrine, it is expected that all water users will suffer water shortages on a frequent basis.
- If the watershed employs the prior appropriation doctrine, it is assumed that the water users who first initiated their water use (agrarian users and cities to the extent of the historic demands) will be satisfied and newer users (eco-tourism, instream flows and junior water rights developed to meet the demands of the increase in population and new commercial-industrial users) will be curtailed from making diversions during certain low flow periods.

By this example, the stress placed on a watershed exhibits how the choice of water laws impacts water use in times of shortage. Water laws are the mechanism whereby a shared, finite resource is managed and allocated between those having a right to the use of water. The laws are necessary to assess and manage the risk of allocated waters in times of shortage. Risk is reduced and disruption can be avoided if water security is rewarded in the form of a water right that carries a preference and avoids curtailment in the event that available supplies are reduced. Getches, D. (2009). In some jurisdictions, certain uses are deemed interruptible while others are not. *Id.* In prior appropriation doctrine jurisdictions, the senior water rights enjoy this preference and hence rise in value. *See* e.g. Colorado Revised Statutes § 37-92-301. Under market conditions, one may plan to avoid interruption by acquiring senior rights to take water. The market becomes the adaptive means by which the impacts of climate change are planned for and mitigated. Tarlock (2002).

In addition, available engineering, land use, political and elective variables can be employed to adapt to shortages, with many of the variables being available to be modified from existing conditions:

PHYSICAL VARIABLES:

Population: Population and corresponding water use will increase by up to 40% in the larger city.
Energy-Water Nexus: Additional energy needs will be required to meet the increase in population, new commercial establishments, infrastructure construction and energy-intensive chip manufacturing plant.
Food-Water Nexus: Additional food sources will be required to meet the increase in population. A longer growing season will extend and increase the water required to applied irrigation use.

Surface Water Availability: Surface water availability will dramatically change. Less precipitation will fall in the form of snow, which is held in snowpack and runs off over a period of time to satisfy irrigation, domestic, municipal and industrial uses. Greater reliance then will be placed on surface water storage and/or groundwater.

ELECTIVE, POLITICAL & CULTURAL VARIABLES:

Water Provider Service Areas/Cooperation: As growth occurs, service areas expand. Agricultural lands may be displaced with development resulting in less applied irrigation water needs. Opportunities may exist to combine or cooperate between service providers to utilize excess capacities and/or sources so as to mitigate new infrastructure or diversions.

Waste Water Provider Service Areas/Cooperation: Service areas are increased. With reduced stream flows and modified run-off patterns, treatment costs may increase to meet increased treatment standards.

Land Use Patterns: Land use patterns as a result of urban growth impact groundwater recharge, irrigation return flows, storm water run-off.

Politics & Economics of Growth: Additional monies and taxes are generated to allow for construction of infrastructure to serve growth and increased treatment. Balancing these costs to assure that “growth pays its own way” becomes important to not create a hardship on existing users.

Surface Water Storage: The reduction in water held in snowpack, increased demands for agricultural water due to food requirements and an extended growing season and increased need for water for thermo-energy production require additional water storage to be constructed. This potentially conflicts with the eco-tourism economies in the remainder of the watershed.

Industrial/Commercial Base: With the larger city moving toward an economy based in large part on chip manufacturing, water diversion and consumption patterns are modified.

Instream & Environmental Flows: As demands in the lower basin increase, flows in the lower basin become insufficient to satisfy demands. The lower flows increase waste water treatment costs. The larger city in need of additional water supplies and production of energy, announces plans to tap additional supplies in the upper basin by construction of a new hydroelectric dam and diversion facilities. This plan impacts instream flows, eco-tourism and the stream hydrograph.

III. APPLICATION OF THE WAAM VENN DIAGRAM

Using the WAAM adaptive management variables described above, many options are available to meet the change of conditions caused by population growth and climate change. Notably:

- If geology permits, conjunctive use may allow subsurface water storage in lieu of surface storage (or reduce the footprint for such);
- If groundwater is available and can be extracted at a rate that equals or is less than recharge, some uses may switch from surface supplies to ground water supplies, often with reduced treatment costs;
- Utility practices and conservation may be employed to reduce the impact of the growth and rise in population;
- Agricultural water uses may be able to be reduced by increasing irrigation efficiencies (and the cost thereof paid for by the downstream municipalities that benefit by such conservation);
- Fallowing agreements may be employed by municipalities to meet dry year conditions by paying farmers not to farm and to loan their water during some low-flow periods;
- Municipal pump-back of partially treated effluent may decrease agrarian fertilizer costs, reduce pollution from fertilizer runoff, reduce treatment costs of municipal effluent and reduce the agrarian water consumption that has now switched to effluent reuse.

If these measures are still insufficient to meet the demands, then broader based approaches that may impact cultural, economic or environmental variables may be weighed against the costs and benefits of approving the new commercial and industrial uses. The variables identified are not inclusive of every possible factor influencing demand and supply. They are to be added to, changed and modified as time demonstrates a need. This is the basis and strength of AWM. Only though a flexible approach, re-assessed on interval timeline which approximates changes in the conditions of a watershed can water supply planning be effective to meet the challenges of climate change and population growth. Pahl-Wostl et al, (2009).

H. Conclusions & Significance

The earth's climate is changing. Regardless of whether man or nature are, or share, the causation, water resource managers must take into consideration the effects of predicted climate change impacts on water availability and demand. Water resource managers interested in adapting to climate change have expressed frustration that the projections on regional changes are not precise enough to support incorporating climate change into regional and local decision-making – particularly decision-making involving large financial investments. The current ranges of projected changes either cover too wide a range to be useful for policymaking, or fundamentally conflict on whether various elements will increase or decrease. For example, David Behar of the San Francisco Public Utilities Commission recently noted that "climate change predictions need to become more actionable for water utilities to be able to act on them". Barsugli and Anderson (2009).

However, water resource managers cannot ignore the implications of climate change until trial-proven scientific data on the precise affects of climate changes exists. Changes are anticipated to be subtle and compounding in nature. Forecasting impacts will be imprecise at best. In conjunction with scientific data and watershed modeling, water managers should affirmatively begin and continue to transition to AWM practices. In collaboration with climate change scientists, engineers, political leaders and community stakeholders, they should develop tailored lists of current institutional, physical and elective-political-cultural variables that are relevant to their managed watersheds, and start to predict variables that may change or come into play as the affects of climate change manifest. Water Managers should also begin to understand how these variables play off of one another, and how they affect water supply and demand. Until we know more about the causes, sequences, direct manifestations and scale of climate change, a WAAM-like water development, use and planning strategy could help practitioners improve their capacity to cope with a changing natural environment and stave off serious water dilemmas.

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