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Proceedings of the Piloting Utility Modeling Applications Workshop

This report summarizes the information and ensuing discussions from a workshop conducted on December 1-3, 2010. Representatives from the Water Utility Climate Alliance and collaborating climate scientists met to exchange information on participating water utilities modeling efforts to incorporate climate change, and how they have modified their planning structure to accommodate this new uncertainty, while climate scientists provided updates on global climate modeling efforts and available climate modeling tools. This report will be a resource to participating entities as they embark on the Piloting Utility Modeling Applications initiative which will attempt to answer questions about selecting climate modeling tools for the applied water sector and how to successfully collaborate with climate scientists to increase the usefulness and the use of climate research in a manner that leads to “co-production” of knowledge.

WUCA
Water Utility Climate Alliance

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Introduction

The Piloting Utility Modeling Applications (PUMA) project for the Water Utility Climate Alliance (WUCA) is an outgrowth of several activities. The first effort included two white papers, commissioned by WUCA, to describe how global climate models and downscaling techniques can be improved to support water utilities' decision-making processes, and how those decisions could be improved given uncertainty. The second effort was the Aspen Global Change Institute workshop on climate modeling, held in September 2009 with participation by WUCA members, federal climate modelers, and climate scientists. Third, PUMA builds on recent discussions of a "National Climate Service" to explore how climate information and analysis can most effectively be provided to practitioners and other potential end users of this information. Finally, PUMA serves as an opportunity to demonstrate different models for how utility managers and climate researchers can successfully collaborate on increasing the usefulness and the use of climate research in a manner that leads to "co-production" of knowledge.

The identified goals of the project are as follows:

- Identify state-of-the-art climate modeling tools and techniques for use by a select group of WUCA members committed to conducting and technically prepared to conduct climate change impacts assessments for their systems.
- Frame the value proposition of these climate modeling tools by articulating the uncertainties embedded in modeling results, as well as how to best use downscaled and other climate modeling data in planning.
- Acquire climate projection data utilizing the identified modeling tools in a form and scale that can be used by utility hydrologic models to generate watershed and/or urban runoff information to be utilized in impacts assessment, water planning processes, and decision making.
- Build a national collaboration amongst the National Oceanic and Atmospheric Administration's (NOAA's) Regional Integrated Sciences and Assessment (RISA) participants and enhance RISA connections by engaging RISA experts from the NW, Cal-Neva, SE, and NE RISA programs in the project, corresponding to the regions for the subject utilities.
- Inform developing conversations between climate science users and providers regarding how existing research meets or does not meet the needs of the adaptation community, how future investment in research might better serve society, and the nature of climate services needed on the ground in communities facing adaptation challenges.

Several WUCA utilities will engage in pilot studies as part of this project. The work will be done in collaboration with RISA centers and a Modeling Advisory Committee (MAC) made up of top climate science experts from around the country. This project provides a forum for engagement between practitioners and scientists in the absence of a national climate service and may even help define constructive paths forward for a national climate service. The hope is that these efforts contribute not only to the individual utilities' planning, but inform the larger WUCA group, and ultimately the entire water sector.

On December 1-3, 2010 representatives from these collaborating agencies met in person to discuss the goals, expectations, and potential challenges for the PUMA project. This included an overview of the participating water utilities modeling efforts and planning structure as well as an update on the status of global climate modeling efforts and of climate modeling tools currently available. Discussion focused on general synthesis of these efforts and region-specific actions that can be pursued through PUMA. This document summarizes the information and ensuing discussions from this workshop as a reference document for use by the pilot utilities and RISA programs as they move forward on their respective collaborations.

Work Produced in Advance of Workshop

Each participant group in the workshop – utility managers, RISA leaders, MAC members – was asked to produce information for the group in advance of the San Francisco workshop. Utility managers produced 4-5 page Utility Briefing Papers, which outlined the nature of their water supply systems and the hydrologic, system operations, and other tools they currently use to model those systems. For the RISA community, the Climate Decision Support Consortium asked Darrin Sharp of the Oregon Climate Change Research Institute to produce an overview of climate modeling tools most widely used to evaluate climate change. This paper, entitled "An Inventory of Approaches to Climate Modeling and Downscaling," was reviewed by MAC members, who were then asked to respond to a ten question survey. This survey provided PUMA participants with MAC familiarity and perspectives regarding these tools and others not covered in the paper. MAC members expressed opinions regarding statistical vs. dynamical downscaling, the availability of "actionable science" as WUCA defines it, the relative advantages of CMIP3 and CMIP5 databases, and other subjects. These documents all helped workshop participants begin with a common set of understandings on a host of key issues.

Background on Water Utility Systems, Models, and Climate Data Needs

Five utilities, including Seattle Public Utilities (SPU), Tampa Bay Water, San Francisco Public Utilities Commission (SFPUC), the New York City Department of Environmental Protection (NYCDEP), and the Portland Water Bureau (PWB) elected to work with RISAs to integrate the latest global climate data into their established system models. These utilities vary in the types and scope of models they use, but all have well-developed modeling "ecosystems" set up to inform decision-making, operations, and planning. These modeling ecosystems can, in theory, accommodate climate data, and the decision-making context is receptive to such integration. However, incorporating climate data into these schemas will involve a fair amount of "tweaking" that may differ substantially from one utility to the next. Most of the PUMA utilities prefer to build in-house capabilities and capacity to tailor climate data to their needs and integrate it into their decision-making tools.

At this December workshop, each of the five utilities presented details of their utility history, customer base, water resources, political context, modeling tools, and past investigations into climate change. This information is summarized below. A table is included for each utility, listing the primary in-house models and their required inputs, scales, and ability to use climate data. Generally, all water utilities have multiple models that perform operational, supply, system simulations or a combination of the above. Each model requires different inputs at different scales, and may or may not be capable of using temperature and precipitation outputs from climate models.

Seattle Public Utilities

SPU serves 1.4 million retail and wholesale customers. The main water sources for Seattle are the Cedar River, which is unfiltered, and the South Fork Tolt River. SPU has two well fields that are available to supplement these river sources during peak demand seasons and emergencies. SPU is currently implementing a Habitat Conservation Plan for its Cedar River Watershed and has a settlement agreement with the Muckleshoot Indian Tribe regarding diversions on the Cedar River.

SPU identified the following challenges for their utility that may be affected by climate change and thus important to consider during PUMA:

- Impacts on supply through changes in snowpack, temperature and precipitation, including any potential changes to the return of fall rains;
- Impacts on water quality through extreme events;
- Frequency and extent of forest fires.

Table 1 lists the main utility models, their use, temporal and spatial scale, input and output parameters, as well as the ease in which they can use GCM data.

The questions focused on how much SPU had "played" with the climate data, what planning horizons were relevant to SPU, which utility outputs communicated to which audiences, whether the paleoclimate record had been considered in utility planning efforts, what could trigger "emergency" actions by SPU, and the extent to which the utility had examined climate change effects on demand. SPU noted that they had not included "black swan" events, such as 3-, 4-, or 5-year droughts, in their planning efforts. They have had difficulty defining probabilities on the dry-end tail of the climate conditions probability distribution and suggested that the difficulty in defining such conditions (e.g., the 500-year or 1,000-year event) meant that such information is not relied upon in operational planning.

Table 1. Primary Utility Models used by SPU

Utility Model	SEAFM and HFAMII	CUE	DHSVM
Use	Rainfall-runoff model used in operational forecasting and operations planning	Water system model used in water supply planning. Provides information regarding overall site performance, optimize multi-sources, determine yield from new supply alternatives, long term flood management, different management triggers (different pumps, well fields)	Hydrology model used in climate impact water demand study
Considerations	Assumptions are made about input wind speed, solar radiation, and lapse rates		Developed by UW CIG, not an in house model
Geographic Scale	203 km^2 (Masonry Dam watershed on Cedar River)	13.8 km^2 to 203 km^2	[Unknown]
Input Timestep	Hourly	Weekly- averaged inflow data	[Unknown]
Output Timestep	Hourly, Daily	Weekly	[Unknown]
Input Params	Meteorological data: min/max air temp, precip total, wind speed, solar radiation, and lapse rates	Unregulated inflows for Cedar and Tolt River systems	Meteorological data
Output Params	Soil moisture, snow water equivalent, streamflows, and reservoir levels	Firm Yield	Streamflows
Planning Horizon	Variable short term: Daily - Weekly depending on mode of use (Probabilistic Forecast, Forecast, or Calibration)	Annual, years	Annual, years
Can this model use GCM/RDM data output directly	Yes	Cannot use climate model outputs directly, but can use climate impacted SEAFM results, or DHSVM results as input	Yes
Has utility used this model in any climate impact studies[a]	Yes - Used downscaled GCM data to analyze potential impacts to SPU's water supply	Yes – used climate impacted DHSVM output	Yes – Statistically downscaling study of three future scenarios to produce climate altered streamflows for four time periods (2000, 2025, 2050, and 2075)

SEAFM: Seattle Forecast Model; HFAMII: Hydrocomp Forecast and Analysis Model II; CUE: Conjunctive Use Evaluation; DHSVM: Distributed Hydrology, Soil-Vegetation Model; UW CIG: University of Washington Climate Impacts Group

[a] SPU has conducted climate impact and adaptation assessments. Section 2.1.4 of the WUCA white paper, "Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change" provides a description of these activities.

Tampa Bay Water

Tampa Bay Water is a regional water supplier serving over 2.4 million customers. The utility relies on a combination of groundwater (50 percent) and surface water sources (50 percent), including seawater desalination. The surface water bodies and groundwater system in the Tampa Bay region are highly interconnected; therefore, the utility uses an integrated hydrologic model (IHM) approach that enables simulation of both surface-water and ground-water. Although sea level change is a very real issue for the southeast coast of Florida, the Tampa Bay region has enough topographic gradient to limit this potential impact of climate change, based on current understanding of sea level rise in Tampa Bay.

Tampa Bay Water identified the following challenges for their utility that may be affected by climate change and thus important to consider during PUMA:

- Climate impacts beyond 25 years on demographics and population, as year to year variability in climate is driving uncertainty now
- Understanding multi-year variability (alternating dry and wet periods) is critical to supply reliability - this region is highly susceptible to climate change because 60% of total annual rainfall comes during four months of the year
- Uncertainty around simulating or predicting El Niño Southern Oscillation (ENSO) as this is a principal driver of multi-year rainfall variability.
- Problems arising from extreme weather events, such as hurricanes
- How to frame climate issues to board members, other elected officials, regional regulatory agency, and community in general
- How to emphasis the importance of making long term infrastructure decisions today that may be impacted by climate 30, 50, or 100 years in future
- How to make good decisions given uncertainty?

Table 2 below provides a brief description of the main utility supply models, their use, temporal and spatial scale, input and output parameters, as well as the ease in which they can use GCM data. Tampa Bay Water also has two types of demand projection models, one for annual and long range planning and the other for weekly to monthly demand projections. Both types of models use rainfall and temperature data. GCM data could be incorporated into the agency’s demand forecasting models.

Table 2. Primary Utility Supply Models used by Tampa Bay Water

Utility Model	**INTB**	**Rainfall-Runoff Stochastic Models**
Use	This is an Integrated Hydrologic Model (IHM). IHM couples HSPF, which simulates surface water, and MODFLOW, which simulates ground water. Used in supply planning	Statistical approach produces streamflow forecasts used in monthly, seasonal and annual water supply allocation decisions
Considerations	Does not consider salt water intrusion	For each future climate scenario, 1000 ensembles of 300 years are simulated Provides probabilities of likely futures climate states
Geographic Scale	4000 mi^2	Hillsborough River watershed: 650 square miles Alafia River watershed : 422 square miles
Input Timestep	15 min, Daily	Daily
Output Timestep	Daily, Monthly	Daily, Monthly
Input Params	Meteorologic data	Meteorologic data (100 years of historic rainfall from three rainfall stations, or simulated rainfall based on historic streamflow characteristics)
Output Parameters	Evapotranspiration, streamflows, spring flows, and ground water levels	Streamflows
Planning Horizon	Variable	Monthly, seasonal, annual for 2-25 years
Can this model use GCM/RDM data output directly?	Yes	Yes
Has utility used this model in any climate impact studies?	Study in progress - In collaboration with University of Florida, they are planning to use downscaled reanalysis data and climate projections of rainfall and temp as input	They use seasonal forecasts of ENSO conditions and observations of rainfall in models to produce probabilistic forecasts of river flows based on the climate outlook

INTB: Integrated Northern Tampa Bay; IHM: Integrated Hydrologic Model; HSPF: U.S. Environmental Protection Agency's Hydrologic Simulation Program--Fortran; MODFLOW: finite-difference groundwater flow model

San Francisco PUC

SFPUC operates the Regional Water System, which services a population of 2.5 million in San Francisco, Santa Clara, Alameda and San Mateo counties. On average 85% of the water provided to SFPUC customers comes from Sierra Nevada snowmelt stored in the Hetch Hetchy Reservoir located on the Tuolumne River in Yosemite National Park. The remaining 15% of water comes from runoff in the Alameda and Peninsula watersheds in the San Francisco Bay Area.

SFPUC identified the following challenges for their utility that may be affected by climate change and thus important to consider during PUMA:

- Under permit from California Department of Public Health, SFPUC operates the Hetch Hetchy system as an unfiltered water supply
- Structure of water entitlement makes SFPUC sensitive to climate impacts
- How should downscaled GCM data be applied to mountainous watersheds such as in the Tuolumne river basin, where temperature and precipitation are sensitive to elevation and daily minimum temperatures are so important for modeling snowmelt?
- How to best apply climate model predictions and various sources of model uncertainty in the HFAM II hydrology model the SFPUC is currently calibrating?

Table 3 below provides a brief description of the main utility models, their use, temporal and spatial scale, input and output parameters, as well as the ease in which they can use GCM data.

Table 3. Primary Utility Models used by SFPUC

Utility Model	**HFAMII**	**HH/LSM**	**HHW**	**HEC-HMS**	**HSPF**
Use	In development-Surface water model to be used for water supply planning	Mass balance water supply planning model used to simulate operation of Hetch Hetchy facilities, Don Pedro Project, Bay Area reservoir, conveyance, and treatment system	Statistical regression model used in seasonal operations. Forecasts seasonal flow on the Tuolumne River.	Rainfall-runoff models for various watersheds	Rainfall-runoff models for various watersheds
Considerations	Selected HFAM - which uses land segments - because of Don Pedro land use (irrigation)	Includes watershed runoff forecasting routine for water supply and power generation allocations	Expressed in terms of probability range and an estimated time-distribution of runoff through the end of the water year. Assumes future climate conditions equivalent to history	Currently in various stages of development	Currently in various stages of development
Geographic Scale	459 mi^2 (Hetch Hetchy watershed on Tuolumne River)	459 mi^2 (Hetch Hetchy watershed on Tuolumne River)	459 mi^2 (Hetch Hetchy watershed on Tuolumne River)	Watersheds of the San Francisco Bay Area	Watersheds of the San Francisco Bay Area
Input Timestep	Hourly	Monthly	Variable, aggregated to monthly	Daily	Hourly
Output Timestep	Hourly	Monthly	Monthly	Daily	Hourly
Input Params	air temp, dew point, temp, precip, solar radiation and wind speed	Unimpaired runoff (1920-2002), accumulated precip, empirically calculated monthly evaporation rates, simulated drought scenarios[a]	Air temp, precip, snow water content, snow depth	Air temp, precip	Air temp, precip, wind speed
Output Params	temp and precip, runoff, snow pack, evapotranspiration, and soil moisture	Reservoir storage, releases and stream flows, water deliveries	Stream flow (in total volume between date of forecast and end of snowmelt season in July)	Runoff	Runoff
Planning Horizon	Daily, weekly, monthly	Monthly	Seasonal	Seasonal	Weekly
Can model use GCM data output directly?	Yes	No	No	No	[Unknown]
Has utility used model in climate impact studies?	No	No	No	No	[Unknown]

HFAMII: Hydrocomp Forecast and Analysis Model II; HH/LSM: Hetch Hetchy/Local Simulation Model; HHW: Hetch-Hetchy Water and Power Project; HEC-HMS: U.S. Army Corps of Engineers' Hydrologic Engineering Center-Hydrologic Modeling System; HSPF: U.S. Environmental Protection Agency's Hydrologic Simulation Program—Fortran

a. Longest drought on record followed by the deepest drought on record used because agency decision-makers are comfortable with this level of conservatism in planning. Also note that East Bay Municipal Utility District planning includes a design featuring their worst drought of record – 1976 through 1977 – and then adds 1977 to the end to create a worst-case-scenario three-year drought. It was further noted that SPU and PWB have utilized these types of design scenarios, but Tampa Bay Water has not.

NYCDEP

The New York City water system supplies drinking water to over eight million people in New York City and about one million people in upstate counties. The system consists of the Croton watershed (10 percent) and the Delaware/Catskill Watershed (90 percent). The water is supplied from a network of 19 reservoirs and three controlled lakes that contain a total storage capacity of approximately 2 billion cubic meters (580 billion gallons), equaling about 2 years of storage capacity.

NYCDEP identified the following challenges for their utility that may be affected by climate change and thus important to consider during PUMA:

- Filtration Avoidance Determination for the Delaware/Catskill Watershed is primary objective (Croton Watershed will require filtration as of 2012)
- How will the frequency and intensity of extreme events (namely intense precipitation) change in the future? And how do we downscale GCM data to represent changes in these extremes?
- Stream and reservoir turbidity levels, which equate to water quality

Table 4 below provides a brief description of the main utility models, their use, temporal and special scale, input and output parameters, as well as the ease in which they can use GCM data.

Table 4. Primary Utility Models used by NYCDEP

Utility Model	**GWLF**	**SWAT**	**OASIS**	**CE Qual-W2**
Use	Variable Source Loading Function Model- is a watershed loading model that simulates daily water, nutrients, and sediment loads from non-point and point sources	Same as GWLF	Operating (mass balance) model simulates water quantity and flows, but does not consider water quality. Evaluates long-term operating rules	A 2-D reservoir model to simulate transport of turbidity through Catskill system
Considerations	Forecasts quantity and quality of water	Forecasts quantity and quality of water and can simulate biogeochemcial processes	Reservoir status is static	(They also use a 1-D reservoir model to examine nutrient loading and eutrophication) Currently, NYCDEP is developing an integrated OASIS and CE Qual-W2 model
Geographic Scale	1972 mi^2	1972 mi^2	5100 km^2	100's of mi^2 , 25 km^2 grid cells
Input Timestep	Daily	Daily	Daily	Monthly
Output Timestep	Daily	Daily	Daily	Monthly
Input Params	meteorological data: air temp, dew point temp, precip, solar radiation and wind speed	meteorological data, and soil, elevationa and land use	meteorological data, reservoir inflows, reservoir/conveyance characteristics and constraints, supply and storage goals (demands in NYC and in northern supply area), operating rules	meteorological data, gauged tributary flows, operations data, and stream temperature measured as a function of air temperature
Output Params	Streamflow, evapotranspiration, as well as dissolved and suspended substances (e.g., nutrients and sediment), and erosion	Streamflow, erosion, dissolved and suspended substances (e.g., nutrients and sediment)	Streamflow	transport and turbidity
Planning Horizon	Weekly, monthly, annually	Weekly, monthly, annually	Daily	1 - 6 month forecasts
Can model use GCM data output directly?	Yes	[Unknown]	[Unknown]	[Unknown]
Has utility used this model in climate impact studies?[a]	Yes. They bilinearly interpolated AR4 GCM data using NCAR Command Language (NCL: www.ncl.ucar.edu), and regridded to 2.5 deg scale, they used a change factor (CF) approach to project future emission scenarios (SRES A1B, A2, and B1)	[Unknown]	[Unknown]	[Unknown]

GWLF: Generalized Watershed Loading Function; SWAT: Soil and Water Assessment Tool; OASIS: Mass-balance reservoir system model; CE Qual-W2: XXXX

[a] NYCDEP is in the process of conducting a climate impact assessment. Section 2.1.2 of the WUCA white paper, “Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change” provides a description of these activities.

Portland

The Portland Water Bureau supplies drinking water to over 880,000 people. The primary water supply comes from the 102 square mile Bull Run watershed, which lies 26 miles east of the city in the Mt. Hood National Forest. The secondary water supply comes from groundwater wells, located just south of the Columbia River. The groundwater serves as an emergency source of water when the Bull Run supply is either reduced or unavailable due to elevated raw water turbidity or infrastructure damage, and as an augmentation during peak summer demand in years when Bull Run storage alone cannot meet demands. Although typically used for summer augmentation or emergency supply, PWB's annual reliance on groundwater has been as high as 14 percent during any given year.

PWB identified the following challenges for their utility that may be affected by climate change and thus important to consider during PUMA:

- Large growth is expected in area, therefore planning challenges will increase
- Filtration Avoidance Determination is an important objective
- Sewer overflow in extreme events can be problematic
- Increase in groundwater utilization
- The effects of climate change on fish species
- Although water scarcity is not an expected climate impact on their resource portfolio, public perception about how the bureau is addressing climate change is important

Table 5 below provides a brief description of the main utility models, their use, temporal and spatial scale, input and output parameters, as well as the ease in which they can use GCM data.

Table 5. Primary Utility Models used by PWB

Utility Model	Rainfall/ Runoff	DAY	Bull Run Temperature Model CE-QUAL	STM and WEAP	DHSVM
Use	Forecast water supply and storage	Deep Aquifer Yield to forecast groundwater supply, water level drop and particle movement	Bull Run Reservoir water levels and temperatures	Mass balance models used in Supply and Transmission Modeling and Water Evaluation and Planning	Subregional hydrology model developed by University of Washington
Considerations	Used in summer supply planning	Models all aquifers used by the Portland GW system and all aquifers in the Portland Basin	Used to predict the impact of reservoir operation on water levels and release temperatures	Can use outputs from bureau's water demand forecasting and from hydrologic models (once developed)	Developed by UW, not an in-house model For 2002 climate study, only used a single National Weather Service station at the Portland Airport
Geographic Scale	102 mi^2 (Bull Run watershed)	1000 square miles	(area of reservoirs)	370 km^2	370 km^2
Input Timestep	Daily	Varies	Varies	Daily	Daily
Output Timestep	Daily	Varies	Varies	Daily	Daily
Input Params	air temp, precip	Hydraulic conductivity; recharge; well pumping rates; initial water levels	Inflow rates and temperatures, air temperature, solar radiation, wind speed, reservoir release amounts	Streamflows calculated from DHSVM, daily M&I demand, minimum streamflow requirements	air temp, precip, vegetation height, soil depth, elevation, slope and slope aspect
Output Params	Runoff	Aquifer Yield; Water level drop; Particle movement	Reservoir velocities, water levels, temperatures	Annual minimum storage, groundwater pumped, length of drawdown, unmet demand	Streamflow
Planning Horizon	Seasonal	Varies; can be daily, weekly, monthly	Seasonal	Annual	Weekly, monthly, annual?
Can this model use GCM data output directly?	No	No	No	No, not directly	Yes.
Has utility used this model in any climate impact studies?[a]	No	No	No	Yes. See DHSVM comment	UW applied four downscaled GCMs from AR3 to DHSVM grid to obtain streamflow files, which were then input into STM/WEAP models (The study was finalized in 2002)

[a] PWB worked with UW to develop a climate change study for the Bull Run watershed. Section 2.1.3 of the WUCA white paper, “Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change” provides a description of these activities.

Climate Data Toolbox

Various tools are available to provide utilities with climate information. Among the modeling tools discussed were several of the climate modeling projects, including the World Climate Research Programme's Coupled Model Intercomparison Project, phase 3 and phase 5 (CMIP3 and CMIP5), the North American Regional Climate Change Assessment Program (NARCCAP) regional climate modeling initiative, and Regional ClimatePrediction.net (RegCPDN). Downscaling tools were also discussed, including the use of simple delta techniques which computes either a difference or a percentage change between output from GCM contemporary and future climate simulations, the Bureau of Reclamation/Santa Clara University's Bias Corrected Spatially Downscaled (BCSD) method, the Bias-Corrected/Constructed Analogs (BCCA) approach, and the Multivariate Adapted Constructed Analogues approach. Explicitly left out of this discussion was the role of observations, reanalysis, Parameter-elevation Regressions on Independent Slopes Model (PRISM) data, and paleoclimate reconstructions.

Current Climate Modeling Projects

Numerous climate-modeling projects exist which simulate future climates response to various forcing scenarios. These projects make global or regional (as in the case of NARCCAP and RegCPDN) climate datasets available for public use. Table 6 summarizes the features of four of the most widely used or anticipated projects, which are being considered by PUMA utilities.

Table 6. Select Climate Modeling Projects

	CMIP3	CMIP5	NARCCAP	RegCPDN
Approximate Resolution (degrees unless noted)	**Atmos:** 1.1x1.1 - 4.0x5.0 **Ocean:** 0.2x0.3 - 4.0x5.0	Native model resolution; details TBD	50 KM	25x25KM (Atmos only)
Output Timestep(s) Frequency	3 hrly; mon/daily mean; extreme	3/6 hrly; mon/daily/annual mean	3 hrly; daily	daily; monthly means; count[e]
Domain	global	global	North America	Western North America; Southern Africa; Europe
# Models	23	~35	Regional = 6; Global = 4 (not incl. NCEP); 20 combo's planned	(1) Regional/Global pairing - HadRM3P/HadRM3P
# Output Params	118[a]	404[c]	49	50
SRES/RCP Emissions Scenarios	(3) A2, A1B, B1	(4) RCP's 2.6, 4.5, 6, 8.5	(1) A2	(2) A1B, B1
Time Periods Covered	1850-2000; 2000-2100; 2000-2300	850-2300[d]	1980-2004; 1971-2000; 2041-2070	1959-2010: 2010-2100 planned
Notes	basis for IPCC AR4[b] (2007)	basis for IPCC AR5[b] (due late 2013)		

Source: From "An Inventory of Approaches to Climate Modeling and Downscaling" for the PUMA Workshop, Dec 01- 03, 2010, San Francisco, CA, by Darrin Sharp

[a] "High Priority Output" only; only ocean and atmosphere available

[b] Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report (AR4), Fifth Assessment Report (AR5)

[c] "Priority 1" output only; ocean, land, and atmosphere available

[d] Range dependent on exactly which Tier 1 and Tier 2 experiments are selected

[e] For example, Number of days with Tmax > 30 degC

One of the most frequently used climate project datasets include the data archive of CMIP3 (officially known as the “WCRP CMIP3 multi-model dataset”), which is maintained by the Program for Climate Model Diagnosis and Intercomparison (PCMDI) at Lawrence Livermore National Lab (http://www-pcmdi.llnl.gov/about/index.php). The CMIP3 archive consists of the output of 23 global climate models from around the world run using the same baseline assumptions under various forcing scenarios. CMIP5 is the next evolution of the CMIP3 project.

Global climate model data have been updated with improved physical relationships and finer resolutions in CMIP5. Among the improvements seen in the CMIP5 data is the development of “time slice” simulations, which are short simulations at fine resolution. CMIP5 will focus on providing increased daily model output compared to CMIP3, which could be useful for utilities. CMIP5 also includes a special project on “decadal predictions” that will use climate models to simulate climate on an intra-decadal timescale. This effort could reduce uncertainty about shorter time horizon climate events such as the El Niño Southern Oscillation (ENSO). Furthermore, the CMIP5 models have used a different set of greenhouse gas emissions scenarios based on “representative concentration pathways” (RCPs), instead of socioeconomically-driven scenarios. There is a general sense that this change will mean very little because several of the RCPs align quite closely with the IPCC Special Report on Emissions Scenarios in current use. More CMIP5 models have included dynamic vegetation types that respond to climate change, but this modeling capability will not be at a scale useful for the purposes of water utilities.

Although there are more models in the CMIP5 process – around 35 for CMIP5 compared to 22 for CMIP3 – that could yield better uncertainty quantification, more models will most likely increase the range of results. Although these models may increase climate variables with greater accuracy, users should not expect increased precision from the new models. Although the CMIP5 model outputs have improved over previous models, climate modelers urged utilities not to expect dramatically improved results. Some mistakes are inevitable, and early adopters of CMIP5 data should expect to face some problems over the first six months or so.

One drawback for the PUMA utilities interested in using the CMIP5 data is the timeframe not only for release of the data, but for the quality control process. For those utilities in a hurry to get work done, CMIP3 data are a better option, but if daily output is needed, waiting for CMIP5 may be better. Instead of choosing one or the other, the utilities might try a hybrid approach by starting a study using CMIP3 data and moving to CMIP5 data as they become available. For those utilities that have already used CMIP3 (SPU) or earlier generations, they may want to wait until the CMIP5 data have been reviewed before incorporating it. Utilities may also want to consider the technical differences between using CMIP3 data instead of CMIP5 data, which may be nominal, versus the appearance issues of using “old” versus “new” data, which could be more significant. Using CMIP5 data would enable a utility to state that they have used the same data the IPCC AR5 report used when it is released.   However, more than 50 percent of the data used in AR5 is expected to be based on CMIP3 due to delays in CMIP5 data production. The National Climate Assessment process currently underway is still undecided on whether to use CMIP3 or CMIP5 data.

Even with the greater resolution of CMIP5, the coarseness of the CMIP3 or CMIP5 data is a major limitation for utilities interested in data at the watershed scale. For utilities, downscaled data might still provide more results at finer resolutions for more areas and time periods. Alternatives to the global climate model datasets include the regional scale modeling projects identified in Table 6 (e.g., NARCCAP and RegCPDN).

The NARCCAP project produces high resolution (50kmx50kmx50km) climate change simulations to investigate uncertainties in regional scale projections of future climate and generates climate change scenarios for use in impacts research. The project consists of regional climate models (RCMs) driven by a set of atmosphere-ocean general circulation models (AOGCMs) over a domain covering the conterminous United States and most of Canada. Similarly, the RegCPDN project uses a global climate model (HadAM3P) to drive the regional climate model (HadRM3P). While, RegCPDN uses only one global/regional model pairing, it runs at roughly twice the resolution (25kmx25km) of NARCCAP. A unique aspect of RegCPDN is that instead of models being run on the large computer clusters at a research facility, small pieces of the project are “farmed out” to volunteer computers (desktop PC’s and Mac’s, numbering some 20,000 at the time of the this PUMA workshop). The output timesteps and output parameters for both RegCPDN and NARCAPP vary, as indicated in Table 6.

Current Downscaling Projects

Utilities may use the higher resolution regional climate modeling outputs (such as RegCPDN and NARCAPP discussed above) or, alternatively, global climate model output can be statistically downscaled to spatial and temporal scales that are more useful to water utilities. Statistical downscaling uses empirical relationships between large scaled model output and local observed conditions to produce data on a local scale. Several projects active in statistically downscaling global climate data are identified in Table 7.

Table 7. Select Downscaling Projects

	USBR/SCU	**Climate Wizard**	**NECIA**	**UWisc**	**USGS CASCaDE**	**CRU**	**UW CIG**
Resolution (degrees unless noted)	1/8, 0.5	1/8, 4KM, 50KM	city to regional (1/8)	10 mins	12KM	10 mins, 0.5	1/16; 12KM, 6KM
Output Timestep	monthly	monthly, seasonal, yearly	daily, monthly, yearly	monthly	daily	monthly	3/6 hrly, daily, monthly
Period(s)	1950-2099	1951-2006; 2050s; 2080s	1961- 2099	1961-1990; 2041-2060; 2081-2100	1950- 2099	1901-2002; 1961-1990; 1901-2100	1915-2006; 1950-2100; 3x100
Method/ Algorithm	bias correct/ interp. (spatial)	various (USBR/ SCU, CRU)	Bias correct/ interp.; regress., prob. dist.	bias correct/ change factor	constructed analogs	interp. change patterns, etc.	BCSD, (Hybrid) Delta; WRF model
Domain	US (1/8); Global (0.5)	US (1/8,4KM); Global (50KM)	NE USA	Global	USA + Columbia R. (Canada)	Global	Western US; PNW
Emissions Scenarios	(3) A2, A1B, B1	(3) A2, A1B, B1	(2) A1Fl, B1	(3) A1B, B1, A2	(2) A2, B1	(4) A2, B2, B1, A1Fl	(2) A1B, B1
Params	precip, surface air temp	avg air temp, precip	min/max/ avg temp; precip; extremes	avg air temp and precip	precip, min/max temp	precip, wet days, temp, wind, etc	temp, precip, winds, soil moist, etc
Data Source(s)	CMIP3	USBR/SCU, PRISM, CRU, CMIP3	CMIP3-GFDL, HadCM3, PCM	CMIP3	CMIP3 - PCM, GFDL	5 IPCC TAR models	CMIP3 (5/10 best)
Notes	48 or 112 scenarios; 16 models					20 change scenarios at 0.5	

Source: "An Inventory of Approaches to Climate Modeling and Downscaling" for the PUMA Workshop, Dec 01- 03, 2010, San Francisco, CA, Darrin Sharp
USBR/SCU: US Bureau of Reclamation/Santa Clara University; PRISM: Parameter-elevation Regressions on Independent Slopes Model; CRU: Climatic Research Unit (at East Anglia University, UK); NECIA: Northeast Climate Impacts Assessment; UWisc: University of Wisconsin- Madison, Center for Climatic Research; CASCaDE: Computational Assessments of Scenarios of Change for the Delta Ecosystem; UW CIG: University of Washington, Climate Impacts Group

These downscaling projects are detailed in the attachment "An Inventory of Approaches to Climate Modeling and Downscaling" for the PUMA Workshop, Dec 01- 03, 2010, San Francisco, CA, prepared by Darrin Sharp. Additional explanation of the common statistical downscaling techniques can also be found in Appendix B of the WUCA white paper, “Options for Improving Climate Modeling to Assist Water Utility Planning for Climate Change”.

Picking the Right Model for You: Climate Tool Evaluation and Uncertainties

Evaluating the array of modeling and downscaling projects can be a difficult task for a utility. An added complexity to choosing climate models is that the ensemble model mean value for a climate parameter does better at reproducing real-world climate than any individual model, yet, by definition, the ensemble model mean is missing all the extremes that could exceed the operational or infrastructure thresholds of a water utility. Attempting to improve climate model information by picking a single model or subset of models based on better physics, better agreement with local climate observations, or other factors may, in fact, lead to worse results. This is because more comprehensive physical representation of the climate increases the degrees of freedom in the model and a thus introduces a broader range of uncertainty. However, eliminating a small number of models with known biases or inaccuracies may be a worthwhile endeavor, even if attempts to figure out which models are best are not effective at this point in time.

In order to evaluate the believability of a climate model’s output, one MAC participant proposed asking three questions: (1) is there a consensus among the models; (2) is the model based on simple physics; and, (3) are predicted trends happening in observations already?

Although there is a broad range of projected outcomes and variables in climate modeling, there is some general consensus among all the models. Knowing these trends will help in evaluation of climate modeling tools. Robust findings across models include statements such as “high latitudes warm more than mid-to-low latitudes,” “land warms more than oceans,” “global mean precipitation increases in a warmer world,” “wet regions become wetter and dry regions become dryer,” and “precipitation intensity will tend to increase.” Climate models cannot yet answer with accuracy the questions of “how much” and “where exactly.”

It is broadly agreed that climate models’ predictions of surface air temperature and sea-level-rise are more certain than prediction of precipitation and extreme event projections. For temperature, a trend is already detectable; for summer precipitation in the United States, climate variability masks the trend to a degree even nine decades out. These year-to-year changes in precipitation are mostly due to long-term, multi-decadal variations such as ENSO and the Pacific Decadal Oscillation. Because of this, it is harder to find a climate change signal in the noise of natural climate variability and models cannot be culled based on historical performance.

Added to the natural variation or internal climate variability is climate model uncertainty and climate scenario uncertainty. Internal variability, model uncertainty, and scenario uncertainty account for different fractions of total variance of model output of temperature and precipitation by region over time. Which of these uncertainties is most significant depends upon the variable one is interested in as well as the forecast time and spatial scale. The comparative signal-to-noise ratios (the mean change divided by the standard deviation) are another way to consider uncertainty in global climate projections by region. Furthermore, these uncertainties “trickle down” into downscaled models.

Challenges for Utility Incorporation

Despite the variety of tools available, questions remain as to whether the available climate modeling tools are ready to support decision-making. Skepticism was expressed about whether these tools can provide the information water utilities need. Several people pointed out that PUMA utilities should first identify what questions each is trying to answer and the associated timeframes/data needs, types of information needed to alter the current course of decision-making, or what methods/information would be sufficient to support decision-making given time/resource constraints. Thinking in this "bottom up" way could generate specific questions to answer instead of scientists having to provide a full distribution of model output.

During the workshop, the utilities did identify a few key climate variables they would like to quantify better. Through various conversations, climate modelers were able to explain and discuss model capabilities and potential issues in predicting the variables of interest to utilities.

Extreme Events

WUCA member utilities expressed interest in knowing whether rain or drought events will become more intense; how intensity, duration, and frequency curves may change; and whether climate tools can be useful for this purpose. These extreme events can push systems to their limits and with aging infrastructure and new regulatory requirements, utilities will face significant upcoming decisions on major capital investments. Extreme precipitation events can also lead to urban drainage problems and associated regulatory compliance issues such as combined sewer overflows (CSOs) and other Clean Water Act regulations. Consideration of climate impacts on urban drainage is a possible "second pillar" of the PUMA study as NYCDEP, SPU, and SFPUC all convey stormwater and wastewater in highly urbanized environments characterized by extensive impervious surfaces in largely built-out yet dynamically changing landscapes. Modeling urban drainage, however, is highly spatially and temporally resolved, with resolutions on the order of 5 minutes and a few kilometers. Additionally, the need for accuracy is important because the difference between an 8-inch rain event and a 9-inch rain event could be significant for urban drainage, while such differences could be negligible for water supply.

These questions pose a very different set of requirements on climate models because climate model simulation of extreme events is less reliable than projections of mean conditions. Identifying trends in a 1:20 or 1:50 year-event increases the data needs of climate models by orders of magnitude, with concomitant costs and data processing requirements. Even identifying the frequency of such events, like those that would trigger EPA thresholds of no more than 1 CSO event per outfall per year, poses significant data production and data management challenges. Although these events occur perhaps six times a year, making them much more frequent than a 1-in-20-year storm, they still fall in the tails of precipitation distributions. It was concluded that separating natural variability from climate change at the scales of interest to water utilities conveying urban drainage cannot be done.

In light of these constraints, three broad directions were discussed as possibilities for urban drainage analysis: (1) a history-based vulnerability analysis, (2) a severe storm conditions evaluation, and (3) high-resolution simulations and downscaling. Workshop participants generally agreed that option 2 would make the most productive use of collaboration between the utilities and RISAs; it is low cost and low effort but might not find anything. Option 1 was deemed a reasonable way to proceed but did not require any specific climate change projection information, and option 3 was deemed very time and resource intensive, with low probability of significant success.

Water Quality Impacts

Four of the five PUMA utilities qualify under the EPA's limited alternatives to filtration rule. The costs of filtration would be so high that maintaining this status is a high priority for these utilities. Thus, in addition to the conventional focus of climate change impacts on water supply, impacts on water quality are also an issue of considerable concern for these utilities.

Decadal Events

ENSO prediction was identified as a specific issue of concern for all of the participating PUMA utilities. Unfortunately, climate models cannot predict the correct timing of ENSO events, although they can predict the correct statistical properties (e.g., amplitude and periodicity). The decadal prediction effort is widely viewed as unlikely to provide conclusive results, leaving intra-decadal prediction as a continuing research area. In addition, the initialization of decadal prediction is being done differently by different research groups, which may lead to an even greater lag time in review and release of that data.

Another utility participant pointed out that since natural variability drives things over the next 10 years, utilities might be in a good place for a while, with time to figure out how to prepare for climate change.

Working with Uncertainty

A further limitation to climate models for utility planning is that some uncertainties may be significantly underestimated due to a number of factors, including (1) the climate community culling climate sensitivities outside the accepted range and (2) looking at model ensembles systematically underestimates uncertainty because each model is tuned to provide the most likely future climate (each climate modeling group is attempting to estimate the peak of the probability distribution function).

Although there may be a desire to quantify model uncertainties, it was suggested that the state-of-the-science simply is not there yet. Climate scientists might provide a confident narrative description of what is going on, but utilities are data-driven and these qualitative explanations may not be sufficient. However, there are options for utilities to work with climate data despite its uncertainties. Because temperature provides so much more confidence than precipitation, it might make sense to see if water resource systems (largely concerned with runoff) might reach a critical threshold based on projected temperature changes alone. Then a set of precipitation scenarios can be investigated to see how changes in precipitation might impose additional impacts upon the more certain impacts caused by temperature changes.

One RISA participant stated that there are fundamental uncertainties that will not go away, even as improvements are made. One MAC member also suggested that even though natural climate variability may be a dominant factor in climate projections, existing utility systems should, in theory, already be adapted to it: this situation was not dramatically different from drought planning. Scientists cannot say when the next drought will come, how long it will last, or how often specific-severity drought events may occur. Nevertheless, the job of the utility participants is still to figure out a way to get through droughts with minimal disruption to water supplies. Likewise, it was suggested that the "solution" to climate change is not narrowing the uncertainties but figuring out how to accomplish utility objectives given the uncertainties that exist.

Next Steps

Each utility will be starting PUMA from very different places. For example, SPU will be building upon multiple completed climate change vulnerability analyses; Tampa Bay Water is currently in the process of developing a directed climate change vulnerability analysis of their water supply; and SFPUC is still in the formative stages of defining what its project will look like. Phase II will document the process each utility undergoes to develop a climate change vulnerability analysis in real time as decisions are being made about project focus, methodology, and other key components.

Utilities + RISA + MAC Members =PUMA

Although there may be some value in getting "answers" from the climate models, there is also value in the process of working with climate experts. These interactions and relationships between utilities and researchers are a valuable part of the PUMA project. It was emphasized that everyone should consider not just what climate models can do directly, but also what can be accomplished with semi-empirical approaches, observational data, and other information sources. As a result of the earlier discussion, participants were able to develop a plan forward for the PUMA project. Each pilot project met with its regional RISA and selected MAC members to discuss modeling approaches, utility assessment goals, and how to integrate climate and hydrologic modeling tools in conducting the water utility assessment.. The groups set some objectives, identified likely climate modeling tools and collaborators for moving forward to Phase II of PUMA.

Earlier in the workshop, the ongoing EPA "20 watersheds project" provided an example of current climate data incorporation into hydrological analysis, which served as a good background for the focused PUMA discussions. The watersheds project goal is to assess U.S. streamflow, nutrient and sediment loading, and the sensitivity of these variables to a number of plausible climate change and land use change futures. In so doing it addresses a number of methodological choices and tradeoffs that could provide valuable lessons for PUMA, including the relative merits of using GCMs, NARCCAP, and BCSD, and integrating climate and hydrologic models.

Tampa Bay Water/South East Climate Consortium

Objectives. Wendy Graham presented some initial results from her replication of the BCSD dataset from GCM output for Florida. This work represents the initial phase of the PUMA pilot project with Tampa Bay Water.

The primary objective is a technical one to study Tampa Bay specifically. A secondary objective is to work with a six-utility consortium organized by Tampa Bay Water to provide education and outreach. The primary objective is to develop and understand the process of using climate projections in the agency's integrated hydrologic models, to look at the results, and to see when and under what conditions such results would inform decisions, such as regulatory permit decisions. Parallel to this effort, it makes sense to focus on communicating the information learned in this workshop to develop outreach materials for the Florida six-utility consortium. It was also suggested that cross-RISA collaboration within the PUMA project timeframe might be important.

Tools. The tools of interest to Tampa Bay Water include CMIP3 (not waiting for CMIP5), NARCCAP, and Florida State University's regional climate model work. Their hydrology model is the Hydrological Simulation Program-Fortran (HSPF), driven by potential evapotranspiration (PET; a minimum-maximum temperature-driven system) and rainfall. Some concern was expressed about NARCCAP using its own PET calculations based on the Variable Infiltration Capacity (VIC) land surface model and whether that would be compatible with the Tampa Bay HSPF hydrology model.

Collaboration. Tampa Bay Water and SECC already have a dynamic relationship. The agency's Integrated hydrologic model is being used by Seywoon Hwang in preparing his doctoral dissertation. The results of his work will be transferred to Tampa Bay Water after he finishes his dissertation.

SFPUC/California Nevada Applications Project

Objectives. The main objective of this breakout session was to establish a dialogue between participants and to develop a mutually beneficial path forward. The second objective was to identify specific goals resulting from this collaboration. To this end utility participants identified the following list: SFPUC would like CNAP to advise them on downscaling CMIP3 or CMIP5 data to SFPUC's observation stations. SFPUC would like advice on applying the delta method, and specifically how to preserve temperature minimums which are extremely important in the Tuolumne River Basin as they define the timing of snow melt. Additionally, SFPUC and Hydrocomp, Inc. would like help from CNAP in modifying the lapse rate used in the surface water model of the Tuolumne River Basin. MAC members would like to see the "real world" application of GCM data and downscaled GCM data in order to make improvements to the GCMs.

CNAP members also identified questions they would like to answer as a result of this collaboration. These include: 1) constraining how temperature changes depend on altitude (in the GCMs), 2) how the onset of the seasonal wet period in the Tuolumne River Basin responds to climate change, and 3) does the emerging CMIP 5 data agree with CMIP 3 data in this region of the country?

Tools. SFPUC is working with Hydrocomp Inc. to develop a surface water model of the Tuolumne River Basin using HFAM II (with plans to have progress made on calibration by end of February). CNAP suggested comparing HFAM II results with the regional VIC model, and then applying GCM results. No decisions were made regarding use of CMIP3 versus CMIP5 data. Additionally, participants were not yet at a decision point in regard to other modeling tools, such as NARCCAP or BCSD. CNAP will be asked to advise the SFPUC on this issue, with a workshop one possible avenue for exploration

Collaboration. Continued dialogue between group members was emphasized. The participants recognized the need to further define the objectives and tasks required to meet the goals. Additionally, the following action items were identified:

- CNAP to send SFPUC a reference list of seminal climate change articles so the utilities can further develop their internal climate change capacity
- CNAP to send SFPUC VIC model references, and
- Continued co-education efforts amongst participants, possibly including a joint meeting.

SPU/PWB/Climate Decision Support Consortium

Objectives. SPU had assessed the impacts of climate change on supply in two previous downscaling studies, as well as the impacts on demand in the second study. In the second study it evaluated a portfolio of adaptation options, including operational adjustments and the effects of continued conservation. This assessment led SPU to decide that it did not have to make major infrastructure investments at this time.

The initial intent of this PUMA effort was to replicate SPU's second climate study, but with a broader range of GCMs. However, based on the workshop discussions, there is an interest in building on the second study by introducing a bottom-up approach to focus the study questions more productively. There are different aspects of the climate models that may be worth exploring, such as decadal prediction and more specific climate changes such as ENSO influences. There are also specific concerns of SPU such as flow regimes for fish and habitat.

There was a parallel discussion of what objectives PWB might bring to a new case study. Portland has alternative water supplies, and its contracts with wholesale customers can be adjusted over time to reflect any observed changes in supply capacity. PWB might be interested in repeating their 2002 study. However, because PWB lacks an in-house hydrology model, interest was expressed in how to develop a hydrologic model based on data and needs such as turbidity, temperature, and water supply. It was expressed that the study questions specific to Portland need to be defined more clearly (e.g., when does the rain end and when does it come back, seasonally).

Tools. Use of CMIP5 data when available is of interest, in part, to maintain credibility. Seattle and Portland have different interests in how the data are developed or used. For example, Seattle is more interested in the potential bottom-up approach. Nevertheless, daily data are needed by both utilities to drive their models. This led to significant discussions about daily scale data, necessary adjustments, biases, and other concerns. Some attention was paid to the relative utility of daily data to drive hydrologic models versus downscaled climate model output.

Collaboration. Participants agreed that the first step in collaboration is to solidify goals and tools. It might make sense to split out the Seattle and Portland efforts because of potentially different goals and needs. They plan to follow up in two months.

Paul Fleming concluded by noting that the PUMA project in many ways is premised on a top-down approach to climate change. However, the top-down modeling assessment envisioned in PUMA could perhaps be initiated within the context of a bottom-up assessment to better determine where to focus the PUMA effort.

NYCDEP/Climate Change Risk in the Urban Northeast

Objectives. The group wants to set up relationships between the RISA programs and the utilities, building communication beyond New York to potentially include Philadelphia and Boston. CCRUN wants to set up workshops in the three cities to discuss the concept of yield over the next 50 years in order to get higher level buy-in for the project. It was noted that this could be a controversial topic given New York City-Philadelphia issues. One important objective is to develop a systematic approach to incorporating climate drivers and downscaling into the utilities' hydrological models. A longer-term objective is to test sensitivity when run through hydrological models.

Tools. The project should develop a consistent modeling approach that is documented with regular communication between modeling groups. A mock process should be developed before CMIP5 data are available so they are ready to go.

Collaboration. It was suggested that a good first step would be to set up a meeting between the several post-docs working with CCRUN and NYCDEP modelers.

National RISA Collaboration

In addition to collaboration between RISAs and WUCA water utilities, collaboration and synthesis among the RISAs could prove effective for the PUMA project. The technical discussions in the workshop proved a useful starting point for this relationship. Each RISA is branded differently, has a different focus and purpose, and brings to the table the specific expertise of its leader. Despite these differences, a fair amount of flexibility exists across RISAs and some cross-regional work has already occurred, including shared funding for RISA-wide program objectives. This funding program could be expanded as necessary and appropriate, but issues may arise if large amounts of RISA funding go outside of the region. Another avenue to facilitate RISA collaboration could come via NOAA's national climate service (NCS). However, since the NCS is still in the planning stages the workgroup participants looked instead to other means of facilitating RISA collaboration, specifically through PUMA.

Next steps for cross-RISA collaboration could include online meetings or phone conferences, surveys like the one sent out for this workshop, exploration of focused topics like NARCCAP, and even some interaction between the climate scientists and the entire WUCA group. This continued dialogue would allow RISAs to share techniques and methodologies for different aspects of the PUMA projects, as well as lessons learned on the process of collaborating with utilities. Although each utility and RISA will have its own unique problems, there may be some overarching technical challenges that could help inform other PUMA projects; the water utilities desire to learn not just from their own pilot project but from the other pilot projects as well.

Since each pilot project will have its own issues and RISA area of expertise, continued collaboration between RISAs may be most productive focusing on issues where the RISA leaders may not be experts, such as how to work with stakeholders, how to develop best practices guidance, and how to communicate effectively. This portends another challenge moving forward with the PUMA project: communicating the science of climate modeling, and tradeoffs for incorporating this into water planning with utility stakeholders.

Communication

Communication to stakeholders of the nuances of climate change science in water planning can be a considerable challenge for water utilities.

The water community needs to know more about what climate change means within a 50-year timeframe in order to make sound investments. However, what is "actionable" is in the eye of the beholder, and utilities may need to justify climate adaptation actions to general managers, boards of directors, and their public.

The definition of what is actionable cannot be divorced from a risk management framework. Technically speaking, all information is actionable depending on the level of risk tolerance. On the utility end, more effort may be needed to articulate what tools and techniques would put utilities in a better position to get better science inputs for water management issues. At the same time, however, utilities should explore risk management techniques to manage the irreducible uncertainty that will accompany decisions about climate change.

It was also noted that "action" can mean a number of things. The formation of WUCA itself was a form of action, but one with a much lower threshold than a $100 million infrastructure investment.

Utilities may need to increase their focus on the appetites and specific interests of decision-makers in this kind of information. Understanding this and getting feedback on what is important to them may narrow the direction planners can take.

Utilities may face operational and engineering difficulties as well. Utilities are still using safe yield curves that do not change with climate information. The outstanding question then becomes whether utilities have to change the engineering paradigm (e.g., is firm yield still a relevant term?). Water utilities may no longer have the luxury of engineering for precision; instead, they must design for flexibility. While some utility participants accepted this as a fundamental underlying shift, these concepts are firmly established in the water community. It was pointed out that we may not yet be in the "era of adaptation", but are perhaps in the "era of assessment."

Additionally, concerns were raised about the willingness of regulatory agencies to accept flexibility in licensing processes, CWA permits, Endangered Species Act regulation, and similar areas.

Another topic explored was the communication of climate change uncertainty to a lay audience. More effort may be needed to educate and convince people that climate change is real. Even communicating uncertainty could be a difficult task because a lay audience often defines uncertainty as "we don't know," while a scientific audience may define uncertainty as "a central value plus uncertainty", in other words, defines uncertainty by using "uncertainty". There is some concern that communicating uncertainty in the wrong way could undermine the work of climate science, including the PUMA project work. Nevertheless, an exploration of uncertainty would make sense to provide in a form useful to decision-makers and the public. A source document developed between the MAC and the utilities describing what the uncertainty question is all about could be a potentially valuable communication document for all the audiences with which WUCA utilities must communicate with. However, internal conversations about uncertainty among utility engineers, operators, and finance people would be a very different conversation than communicating with the general public.

Conclusion

The workshop provided a fruitful forum for directing the PUMA project forward. Utilities may have been familiar with many of the issues presented and may have attempted similar projects in the past, but PUMA provides an opportunity to leverage the knowledge and expertise of a broad set of institutions and people and further advance our knowledge. The PUMA project was specifically designed to enhance the co-production of knowledge by integrating an ongoing dialogue between scientific experts inside and outside the RISA centers and the consumers of that information in the utilities. The knowledge co-produced at the workshop led to some specific lessons and directions to better develop PUMA Phase II:

1. There is a path forward in spite of uncertainties – we understand climate is changing and we are certain about some aspects of change such as higher temperatures;
2. There is no one-size-fits-all application or tool. Careful attention to the information needs of the question at hand, along with a good understanding of the pros and cons of the different methodologies listed above, are necessary to make an informed decision about where or whether to invest limited time and resources. The modeling methods that facilitate decisions are a function of what a decision-maker is trying to accomplish. A technical lesson learned was not to select the best models for a geographic area but to feel free to remove the worst models where the model fails to capture specific processes or phenomena important for a particular region. For example, if it has been decided that the southwest monsoon is of interest, the selection of climate models should be narrowed to those that capture this phenomenon. But otherwise, using a comprehensive ensemble of models is fine.
3. Significant questions were raised about which tools to use and the state-of-the-science in providing actionable information on climate change and tools to support decision-making, and less progress was made on these questions than on some others. More effort is needed to articulate what tools and techniques would put utilities in a better position to get better science inputs for water management issues and create “actionable” information. Until then utilities need to develop an approach whereby they rely on models for some information but not other information. For example, PWB drives its watershed model, which varies from an elevation of 400 feet to 3,000 feet, with a single weather station at 400 feet. Under such conditions there is a tendency to focus exclusively on the impact of climate change in the context of a particular station. No historical data is available on the higher elevations the service area to verify which climate models are more accurately modeling the watershed. However, needing vast elevation change in a relatively small geographic area requires models to focuses on what climate scientists have the least confidence in.
4. Utilities might consider incremental strategies rather than big investments until trends are clearly changing or the modeling tools get much better.
5. The simpler, the better. When it comes to examining climate impacts in conjunction with complex hydrologic models very simple methods might be the best. This was also summarized as a modified KISS principle ☐ keep it sim
   a lot of insight, control, and understanding into the impacts of climate change. Instead of trying to incorporate GCM climate data into hydrologic models, utilities could look at the anticipated change and apply this factor to the meteorological data currently in use. This can be very resource efficient, but there are some downsides in terms of the robustness of the output.
6. Utilities might use a scenario-based approach on precipitation changes while using climate change altered temperature projections.

7. Another avenue for utilities to explore as a means of evaluating climate change on their systems could be risk management techniques. These may help to manage the irreducible uncertainty that will accompany decisions about climate change.
8. It makes sense to first do a bottom-up assessment to figure out what key sensitivities exist before launching into a vulnerability analysis using many of the technical tools discussed at this workshop.

These conclusions and challenges provide a sound and realistic foundation for PUMA utilities as they move forward. Although incorporating climate change variables into water planning has its difficulties, by undertaking this task PUMA participants put themselves in a position of being able to articulate the projected impacts on the system they manage on their own accord and begin the process of informing their adaptation decision-making.