# Written Public Comments on the
## *Strategic Plan for the U.S. Climate Change Science Program*
## Chapter 7: Water Cycle (pp 80-89)
### Comments Submitted 11 November 2002 through 18 January 2003
### Collation dated 21 January 2003

Page 80, Chapter 7 (Please see submission by James Kinter, Chapter 5 for cross-cutting and linkage comments on Chapters 5, 6, and 7)

Page 80, Chapter 7: The following comments are directed to issues relating to land-atmosphere interactions. While these issues are relevant to many of the chapters in the CCSP draft, they are particularly motivated by text in the Water Cycle (7) and Land Use (8) chapters. Overview comments include:

• The CCSP draft correctly infers that the term ”global change” incorporates a change in the frequency distributions of important climate variables. This is more than a change in the mean values. Changes in the frequencies of occurrence of relatively rare, but extreme events, can have very large human implications.

• Consistent with frequency distribution concepts, the scientific output expected from CCSP projects should be amenable to coupling with proven risk management techniques.

• The CCSP draft uses the term ”watershed-scale” without sufficient background. Watersheds can span scales from the hill slope to continental. This raises issues of scale interaction models that are amenable to probabilistic modeling methods discussed elsewhere in these comments.

• A distinction between ”observations” and ”monitoring” should be made more clear in the CCSP draft. The science of global change research requires long-term observations of su_cient precision to permit discovery, quantify process, and support model building. Monitoring comes about after relevant thresholds have been established based on integrations of the science. The monitoring process is used to determine when thresholds are exceeded and remediation is required.

• Regarding observations, the CCSP draft is commendable in recognizing the need for ”coordinated data sets” and datasets from ”regional test beds”. These data entities will require substantial new support for infrastructure, personnel, and instrumentation.

• The interdisciplinary nature of the climate change problem is also recognized in the CCSP draft. What is perhaps not specified is a need to educate di_erently, at the graduate student level, to support CCSP needs. An educational goal is the development of a pool of multi-disciplinary climate change scientists capable of providing syntheses of science results necessary to interface with policy-makers. Also, the numbers of field scientists in training should be examined. A significant fraction of the pool of experienced field experimentalists is nearing retirement. Are their su_cient numbers of appropriately trained young scientists to replace them?

• The balance between observational and modelling emphases in the CCSP seems correct. We note a need for observational datasets su_cient to properly initialize and test mesoscale boundary-layer models and/or boundary-layer components in large-scale models. Such observations should span time periods commensurate with growing cycles in major biomes of specific continents, and eventually the globe.

• CCSP should consider a coordinated network of natural laboratories (an enhancement of the test bed concept in the CCSP draft). For water-cycle and land-atmosphere interaction issues, this coordinated network could consist of nested watersheds of various scales across the major biomes of the US, and eventually the globe. Land-atmosphere interaction research in support of climate change science naturally begins at a minimum resolved watershed scale. As a prototype example, we refer to the Cooperative Atmosphere-Surface Exchanges Study (CASES) that documents land-atmosphere interaction over a 5400 km2 watershed in a grassland biome of the Midwest. In a larger-scale context, we refer the CCSP authors to the Water, Earth, Biota (WEB) white paper that emerged from the Geosciences 2000 e_ort at NSF.

• Natural laboratory creation and maintenance will require substantial resources in time and dollars. The time horizons projected in the CCSP draft for many of the water cycle and land use science deliverables (typically 2 to 4 years), are unrealistically short. Ten year time horizons are more realistic. For example, the data-gathering component of a hydrology program in the CASES study area is 3 to 5 years, with 3 to 5 additional years (partly overlapping) planned for data analyses. The plans for CASES extensions also provide examples of the dollar investments to be required. The e_ort to generate from the CASES observations su_cient datasets for the initialization and validation of atmospheric boundary-layer models will require long-term sta_ng of O(10) technician and field scientist positions. A substantial instrument maintenance budget is also required over the decade long time period. We note that the resource requirement bounds outlined here are for a single natural laboratory.

• The CCSP draft correctly notes that there exists a geophysical component of waterborne (e.g. coastal inundation) and airborne (e.g. dust transport) disease processes. Understanding the relevant geophysics for such processes should be given a higher priority in CCSP.

*References*

for information regarding CASES see: http://www.joss.ucar.edu/cases.
for information regarding WEB see: http://cires.colorado.edu/hydrology

## NORTHWEST RESEARCH ASSOCIATES (NWRA), DR. ROBERT GROSSMAN

Page 80, Chapter 7: The chapter places too little emphasis on three aspects of the water cycle:

(i) Convection seems to be included in a catch-all of clouds and cloud processes, I assume, but presents its own particular problems. These need to be articulated.

(ii) The oceanic freshwater flux that drives salinity changes (both P-E and river runoff). There are some interesting links with water management here via water extraction from rivers, irrigation and so on, which may be changing the partitioning between the ocean and land of P-E.

(iii) The importance of soil moisture in setting the Bowen Ratio and hence land surface feedbacks.

## JULIA SLINGO, NCAS/CGAM, UK

**Comments on Chapter 7**

Page 80, Chapter 7: 1) Two thirds of incident precipitation is evapotranspired, most of that via transpiration. The role of vegetation in the water cycle is almost neglected by the chapter. Under climate change, vegetation will change, potentially under catastrophic disturbance over wide areas. This will clearly affect the water cycle. Vegetation and disturbance change will also affect erosion and water quality. Hydrologic models usually carry rudimentary vegetation algorithms and vice versa. The two communities must work much more closely together in the future to wed the dynamics of the biosphere and the hydrosphere.

2) The changes in societal demands for water, interacting with changes in vegetation and the seasonality of hydrology are not well treated in the chapter. Human populations are expanding into already water-limited areas, overdrafting aquifers. These issues should be considered as the climate changes.

3) There will be competing demands between carbon, fire and water policies. Demands for increased carbon sequestration will increase the fraction of water transpired and reduce that available for human and agricultural consumption, as well as for river transportation. Fire policies demand reductions in fuel loadings, which will have the reverse affect from the carbon sequestration policies. All three issues (and perhaps others) must be considered and modelled in synchrony.

**RON NEILSON, USDA FOREST SERVICE**

Page 80, Chapter 7: First Overview Comment: The term uncertainty is utilized without any clear definition of the term. As this is the main theme of much of the report, it portrays an incorrect image of climate science that everything is uncertain and that no one can or should act until the uncertainty levels are diminished. It then goes on to lay out a high risk strategy of waiting until an unknown day for uncertainties to be reduced before any action can be taken. The risks are high as the lifetime of greenhouse gases in the atmosphere is long and mitigation efforts will not take immediate effect, unlike some other pollutants. This also ignores decades of research by US institutions and others that have reduced uncertainty levels on a wide range of climate issues. A guide to the uncertainty levels is clearly included in the IPCC's Third Assessment Report.
We would therefore strongly recommend that the report and the research efforts around it not revolve around reducing uncertainties per se, but rather provide new and useful information for policymakers. Finally, to infer that policymakers must have 100% certainty before taking any decisions is not consistent with the current situation. As the report notes, there are many uncertainties surrounding terrorism, but the government is not waiting for 100% certainty before taking preventative measures such as increasing security in airports.

**JENNIFER MORGAN, WORLD WILDLIFE FUND**

Page 80, Chapter 7: This chapter addresses the role of water in the climate system and concentrates principally on the response of the hydrologic cycle to climate change. What should be stressed in addition are the serious gaps in our knowledge on the role of hydrologic cycle in the driving of global climate change.

**First Overview Comment on Chapter 7: Is the role of the hydrologic cycle in climate change correctly represented in the models?**

The interaction between the hydrologic cycle and solar radiation is quite different in the two theories of Pleistocene climate change. In the conventional Milankovitch model, the feedbacks between summer insolation and the growing snow and sea ice fields trigger atmospheric cooling. In Tyndall's model (1, 2) a stronger spring insolation increases the warming of the oceans, the equator to poles temperature gradient and the transfer of water to the high latitudes. At the same time, the weaker insolation in boreal autumn facilitates the growth of polar ice and the sea level drop. Increased precipitation in the northern high latitudes freshens the subpolar ocean and affects the thermohaline circulation. Tyndall's theory, contrary to the conventional one, depicts the glaciation process not as a result of cooling, but instead as the outcome of water transfer from the warming oceans onto the cooling land.

Current observations show that the oceans in the low latitudes are warming and the precipitation in the high northern latitudes is increasing. The northern North Atlantic freshened significantly (3). Ice in central Greenland shows regions of thickening as well as thinning. Disintegration of the ice sheet margins has accelerated in recent decades (4,5). Net snow accumulation at the South Pole between 1965 and1994 was higher than any thirty years long average of the last 1000 years (6). A significant increase in the number of winter precipitation events has been reported for the Pacific side of the Antarctic Peninsula (7). Although there is evidence of the retreat of the West Antarctic ice sheet over the past several thousand years, more recent evidence points to the ice sheet growth over the past two centuries (8). Key GCMs have predicted increased snowfall in Antarctica and in the high northern latitudes in the higher $CO_2$ environment (9).

These recently observed changes are raising questions about the nature, significance and impact of hydrologic variations on the global climate system. Can the disintegration of coastal ice lead to the melt of ice sheets and a major rise of sea level? Can the natural warming trend counterbalance the sea level rise predicted from the CO2 models? Can the freshening of surface waters in the northern North Atlantic modify the conveyor belt (10), shut down the thermohaline circulation (11), and consequently cool Europe?

To reduce the uncertainties we propose following research tasks:

- Detailed reconstruction of the history of ocean circulation and surface climate at the end of the last interglacial from paleoceanographic and palynologic archives.

- Modeling of water transfers from the oceans to the ice sheets.

- Detailed modeling of ocean circulation response to the increasing fresh water input to the high latitudes.

- Intensified observations of ice mass balance in Antarctica and Greenland, and of the freshwater budget in the northern North Atlantic. Comparisons with model results.

**References**:

1. J. Tyndall, *The Forms of Water in Clouds and Rivers Ice and Glaciers*, International Scientific Series (the Werner Company, Akron, Ohio, 1872).
2. G. Kukla, and J. Gavin, *Global and Planetary Change* (submitted).
3. R. Gagosian, Woods Hole Oceanographic Institute, http://www.whoi.edu/home/index_education_main.html
4. R. H. Thomas, *EOS* **82**, 369 (2001).
5. W. Krabill *et al.*, *Science* **289**, 428-430 (2000).
6. E. Mosely-Thompson, J. F. Paskievitch, A. J. Gow, L. G. Thompson, *Journal of Geophysical Research* **104**, 3877-3886 (1999).
7. J. Turner, S. R. Colwell, S. Harangozo, *Journal of Geophysical Research* **102**, 13,999-14007 (1997).
8. I. Joughin, S. Tulaczyk, *Science* **295**, 476-480 (2002).
9. H. Ye, J. R. Mather, *International Journal of Climatology* **17**, 155-162 (1997).
10. W. S. Broecker, *Oceanography* **4,** 79-89 (1991)
11. W. S. Broecker, *Science* **278,** 1582-1588 (1997)

## GEORGE KUKLA, LAMONT-DOHERTY EARTH OBSERVATORY OF COLUMBIA UNIVERSITY

Page 80, Chapter 7: **First Overview Comment:** Where are the oceans in this study plan? They are a dominant player not only in the water cycle, but in climate in general. How could explicit research relating to them not be explicitly included.

**Second Overview Comment:** Where is the NAS report? Where is the national assessment? Where is the IPCC TAR? There is a wealth of information out there yet we seem bound and determined to ignore it. In some cases reinventing the wheel or rehashing debates that are already quite mature. Let's take advantage of the wealth of knowledge that does exist and save our effort and funds for the questions that get us to solutions, not those that help us put off solutions.

**Third Overview Comment:** Can we really resolve the uncertainties that the questions this chapter aims to resolve in 2-4 years? Many of these issues have been on-going for decades. To believe that we are now going to really focus and tie it all up is optimistic to put it kindly.

## LARA HANSEN, WORLD WILDLIFE FUND

Page 80, Chapter 7: Page 112, Chapter 10: Overview Comments on Chapter 10 Ecosystems, and Chapter 7 Water Cycle:
I applaud two important components of both these chapters:

a. The emphasis on interactions of climate with human activities, and the emphasis on linkages between all atmosphere and biosphere components (such as atmosphere, oceans, ecosystems and water. The plan appears much more integrated than previous programs.

b. The emphasis on sustained long-term measurements (and the explicit statement that current monitoring efforts are insufficient). Whether on the ground, or via remote sensing, there is inadequate coverage to track changes occurring currently in the water cycle and in ecosystem properties, and not enough information to use as input for models in order to make projections with much certainty.

**JILL BARON, USGS**

Page 80, Chapter 7: Transportation's interest in the water cycle lies in inland shipping and the Great Lakes region. Recent water disputes on the Missouri River highlight the potential conflicts between shipping and other uses of our limited water supply. Good research is essential to inform policy decisions regarding water use conflicts, but the chapter does not list consequences to transportation as a possible impact of changes in the water cycle. More generally, the chapter needs to broaden its focus beyond the possible changes in the water cycle to consider the implications of those changes in arenas such as implications for water ownership, likely use conflicts, harm to ecosystems, etc.

**DEPARTMENT OF TRANSPORTATION, LAWSON**

Page 80, Chapter 7: The ìwater cycleî chapter has an appropriate dual focus on poorly known aspects of the water cycle ñ variability, predictability, linkage with nutrient cycles and ecosystems ñ and water resources. This reflects the best of the USGCRP report cited, and an earlier NRC report from the Committee on Hydrologic Sciences. The lack of adequate data and information systems for the hydrologic sciences was made quite clearly in those reports, and is an area where the CCRI could make an important near-term impact. Many current and historical hydrologic data are not available in usable, publicly accessible archives, and considerable effort will be needed to make them accessible.

**ROGER C. BALES, UNIVERSITY OF ARIZONA**

Page 80, Chapter 7: Page 58, Chapter 5: Overview Comments on Chapters 5, 6, and 7 based on my Panel Presentation

Emphasize exploitation of recent and ongoing programs to demonstrate capability to bridge gap between "Research Needs" and "Products and Payoffs" -- especially for 2-4 year horizon -- e.g., ARM Program, including use by GCIP

Acknowledge gulf that exists between (a) obtaining improved understanding of climate system and (b) having society benefit from this new knowledge -- requirements include substantial "impact data sets", extensive interactions with potential users of mitigation information, and long-term collaboration with social scientists, economists, etc.

Need for greatly enhanced resources if desired progress is to occur -- qualified scientists and institutional funding -- e.g., where are needed people with interdisciplinary expertise?; level of funding of NOAA Laboratories in last 20 years has halved their capability to contribute

**PETER LAMB, THE UNIVERSITY OF OKLAHOMA**

Page 80, Chapter 7: General comment: this chapter would benefit by better drawing the distinction between the importance of the water cycle for the baseline climate, and the fact that many of the research goals here are key for understanding the baseline climate, and those aspects that specifically lead to a better understanding of climate change under anthropogenic forcing. The two may be related, but it's not appropriate to assume that they are equivalent, as is often done in this chapter.

**SUSAN SOLOMON, NOAA**

Page 80, Chapter 7: There is practically no mention of monitoring the changes in surface ocean properties related to the water cycle. Arctic river discharge has been increasing for the last 40 years, the subpolar regions of the North Atlantic have been getting fresher for the last forty years, and now evidence is emerging that the tropical oceans have been getting saltier. The largest component of the hydrological cycle is the ocean, it has been changing for at least the last forty years, and yet it is hardly mentioned in this chapter. There should be a greater emphasis placed on observing changes in the ocean-component of the hydrological cycle.

**WILLIAM B. CURRY, WOODS HOLE OCEANOGRAPHIC INSTITUTION**

Page 80, Chapter 7: Here are a few comments. Most deal with the notion of integration of water cycle science and the global change issues. There is a general lack of experimental and coordinated instrumentation in Chapter 7 too. By this I mean it could use the language of developing a "New Observing SysteM which better integrates instrumentaion and sampling.

The Part II USGCRP Section needs to have a greater integration of Water Cycle issues in almost every chapter as this is what will serve as a basis for new science intiatives beyond those traditional research areas currently underway. A more integrated approach to water cycle science will greatly help the carbon, landuse and ecosystems elements of the plan. Emphasis on integration will also help to define the Decision Support/management and risk issues outlined in Part I. It would also seem appropriate to say something about Decision Support in the Water Cycle Chapter 7.

A second and related aspect that needs strengthening in PArt II USGCRP is the notion of "Integrated Observations" across all elements of the terrestrial water cycle particulary with respect to groundwater and the influence of the water table on soil moisture, vegetation and streamflow.

With respect to Chapter 7: The first Question needs to be rephrased or combined:
1) To what extent is the water cycle accelerating and/or amplifying and what are the internal mechanisms and external forcings responsible?
5) What would be the likely consequences of acceleration and/or amplification of the water cycle on human societies and ecological systems? How can Water Cycle research inform policy, support decision making and reduce risk in water resource management.
<u>Chris Duffy</u>

## USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP

Page 80, Chapter 7: The comments on the chapter by Mark Miller et al. constitute a significant improvement on the document, and forms a good basis to begin revisions. Many of their comments are towards focusing the chapter. My comments below follow their lead, centering on specific elements that are implied but not clearly stated in the White Paper, and in some cases completely absent from Chapter 7.

**Closing of the water cycle over a limited domain:**
This is a program put forward by Duffy and Miller, which I heartily endorse. I trust that they have made comments that better address this issue than I could ever do.

**Enhancement of the observational network:**
This cannot be over-emphasized, and is key to Question 1. It is mentioned in the Research Needs, but should be brought to the front as a critical need. Likewise, in the White Paper, Sec 2.1 mentions the deterioration of the network and a general need for increased *in situ* and satellite observations, but this point is lost among the bullets for Research Questions and Products & Payoffs. Many of the research questions cannot be adequately addressed without that initial investment in improved monitoring of the global hydrologic cycle, including precipitation (mentioned only in the white paper), soil moisture (mentioned in both), river discharge (a rapidly degrading network), water table (I hope Chris Duffy elaborates on this), snow mass, permafrost (both spottily observed but not mentioned), and evapotranspiration (a crucial feedback flux and the trickiest of all to measure).

**Determining observational requirements:**
Improved models and observations are independently called for, but there exists the opportunity to use current models, through observing system simulation experiments (OSSEs), to more intelligently develop and economically deploy enhancements to the observing networks by determining where the greatest feedback sensitivities and most important holes in the observing systems lay. This is an issue for Question 3, which would then directly impact Question 1. In Chapter 7 and the White Paper, there appears to be no connection made that the models have the ability to guide the development of the observing systems.

**Determining the limits of predictability of the water cycle:**
The illustrative questions of Chapter 7; Question 3 leave out the first bullet question in Sec 2.3 of the White Paper, which is “How predictable are water cycle variables at different spatial and temporal scales?” This is a key issue. There is some theoretical upper limit to predictability of any variable at a given space and time scale. A lower bound of this limit can be estimated from models. Current models, fed information from the current observing system, have a practical limit that lies below both this idealized model limit and the true theoretical limit of predictability. These bounds (for both current operational situations and the best case with current state-of-the-art models) have not been well quantified for the water cycle. They should be explored, so that we might find the areas where improvements might be made most rapidly (e.g., observational

enhancement in the OSSE framework), and also to determine where our predictive abilities might realistically be realized. Can seasonal forecasts can ever be useful for water resource managers (for instance)? We can estimate what is the best we can do today, and what is the potential for improved forecasts by determining the limits of predictability of the water cycle.

**Integrated water cycle models:**
Question 2 partially addresses this issue, with reference to "new models" that simulate feedbacks between the hydrologic cycle and climate system, and also in Question 4, the interdisciplinary connection. The idea here is to set a goal of developing an inclusive model where no branch or tributary of the hydrologic cycle is left as a boundary condition. This is a mantle which an individual agency might pick up, perhaps in connection with computing advancements and applications. But only through the exercise of modeling the entire water system can the full system be understood. Paul Dirmeyer:

## USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP

Page 80, Chapter 7: Like the rest of the SSG, I generally endorse the recommendations made by Mark Miller et al., in addition to the recommendations from Paul Dirmeyer regarding integration of the White Paper and Chapter 7 (see above). In particular, I believe that the overarching questions need restatement in a form similar to what Miller et al. recommend. Moreover, I believe that more linkages with the three key cross-cutting areas in Chapter 2 need to be made in this chapter in order to reinforce my comment above—i.e., that prediction of the water cycle underlies all three "key" areas. Finally, I think there should be more explicit links to Chapter 12, which identifies "Grand Challenges in Modeling, Observations and Information Systems", although my comments below indicate that the term "grand challenges" seems somewhat inappropriate. Christa Peters-Lidard,

## USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP

Page 80, Chapter 7: **First Overview Comment:**
The first three questions presented in the chapter are relevant and important climate questions whose history dates back at least a decade. These three questions can be wrapped into two slightly more detailed questions, thereby leaving room for a third question that is timely and more focused. As it stands, the linkage between the questions on the first page and the overarching questions is weak. In addition to the changes that are suggested below, the overarching questions need to be revisited and modified as suggested in later comments.

Suggested Questions (1)-(3)
Question 1: What are the key *global-scale* uncertainties, internal mechanisms, and feedback processes of water cycle variables on seasonal to decadal time scales, and what is their level of inherent predictablity?

Question 2: How do water cycle feedback mechanisms operate *on local, regional, and river-basin scales*, and how do they feedback to other parts of the climate system (e.g. carbon, nitrogen, and energy cycles)?

Question 3: Is it possible to obtain observational closure of the atmosphere and land water and energy budgets *from river-basin to local (watershed) scales* and what are the associated uncertainties in this closure?

Question 4: How do the water cycle and its variability affect the availability and quality of water supplied for human consumption, economic activity, agriculture, and natural ecosystems: and how do its interactions and variability affect sediment and nutrient transports

Question 5: unchanged

There should be a Chapter Question 6: What is the likelihood of changes in extreme event sensitivity and occurrence in space and time and what are the changes in extreme event impacts due to human modifications and water uses (consumptive withdraws and interbasin diversions)?

**Second Overview Comment:**
Climate-driven changes in the water cycle will manifest themselves on local and regional scales, so the principal focus of water cycle research in the near future should strongly emphasize improved understanding of water cycle processes on these scales. Improved understanding of the physical processes at these scales is required for more accurate representations in coupled hydrologic models of all types. To achieve the necessary level of understanding of regional and local water cycles, it is essential to develop well-instrumented regional water cycle testbeds. These testbeds are mentioned in several places in the chapter, but they need to be highlighted and should be a central feature of the research strategy. There are plenty of models of global, regional, and local hydrologic processes, but there is no comprehensive data set from which to validate the models. The riparian (river-scale) water budget has never been balanced in any model because we lack understanding of the regional and local scale processes that contribute to the water budget (Roads et al., 1994; Betts et al., 1998; Roads and Betts, 1999; Betts et al., 1999; Roads et al., 2002). Another contributing factor may be insignificant model resolution relative to the processes that must be characterized and, in addition, our understanding of ground water and soil moisture processes is still not adequate because we have a limited set of observations. They are part of the hysteresis that exists in the climate system, so it is essential to properly understand them on a number of scales. Efforts to discuss the links between global water cycle processes and local impacts hinge on knowledge of the links between local and regional processes. While progress is possible through continued development of coupled and integrated models, such development will be of limited utility until data sets are available for more comprehensive model testing. This chapter should focus on the study of regional and local scale water cycle processes and everything else should be wrapped around this principal activity. We must have an integrated view of the river-basin water cycle, which means a comprehensive set of coordinated measurements at a variety of scales. One of the "illustrative research questions" should focus on the development and implementation of instrument systems capable of performing closure experiments from local to river-basin scales.

**Third Overview Comment:**
The current chapter lacks focus and is inconsistent in terminology. A clear distinction needs to be made between research aimed at understanding the global hydrologic cycle, regional and local water cycle processes, and water quality. Improved understanding of the global hydrologic cycle will require significantly different research than improving regional models of water cycle processes; yet in the current chapter it seems to be folded into a single ill-defined package. The overall intent of the traditional feedback- and process-related research should be improved understanding of local and regional water cycle processes because they are closely tied to the human impacts; a clear progression of research toward this goal is required.

**Fourth Overview Comment:**
On a more basic level, the first of the "overarching" questions emphasizes water quality, cycling of nutrients and toxic substances, and human and ecosystem health, in addition to the "traditional" climate change research emphasis on understanding the global distribution of water and water-climate feedback processes. This water-consumption-based emphasis is reinforced by the second overarching question which highlights the capacity of "societies to provide adequate supplies of *clean* water" (emphasis added). These two questions appear to signal a major change in research focus from the climatic feedback effects of water and its forms (i.e., climate change causes) to research into the "end-use" consequences of changes in the water cycle. If this change was intended, however, it was not carried forward to the chapter-leading questions, only one of which (#4) mentions water consumption issues. This apparent quandary illustrates a key problem with the linkages in the current document between the overarching questions and the questions at the beginning of the chapter.

The overarching questions should be subdivided into two major themes: climate-induced changes in water distribution and the consequences of such a redistribution. *As they currently stand, the overarching questions appear too heavily weighted toward water quality and contain redundant information.* Water quality is a complex issue because the processes that modulate it can occur on extremely small scales, and efforts to simulate water quality on climate scales are dependent on successful simulation of the water budget, which is the first order problem. References to "toxic substances" and "affects on human and ecosystem health" should be limited to the second overarching question. The following overarching questions achieve better separation of tasks:

How do water cycle processes (including climate feedbacks) and human activities influence the distribution of water within the Earth System, and to what extent are changes predictable?
What are the potential socioeconomic consequences of climate-induced changes in the distribution of water? How would these changes link to demographic trends, land use (including changes in agriculture and land management practices), the cycling of important chemicals (carbon, nitrogen, other nutrients, and toxic substances), and local water quality.

## Comments on Chapter 7

Fifth Overview Comment

For many *global and regional* studies of the water cycle to be successful, specific attention needs to be given to the role of the oceans in the water cycle, and in the partitioning of the freshwater flux to the ocean from precipitation, sea-ice melt, and continental runoff. The IPCC community has identified the oceanic meridional circulation (MOC) as a particularly volatile climate process because of its large role in poleward heat transport and the propensity of coupled atmosphere-ocean models to weaken it during $CO_2$-induced warming. Freshening of the high-latitude oceans is believed to be a key ingredient in the weakening of the MOC and the ensuing abrupt hemispheric climate change. There should be a strong emphasis on the world's oceans present in this strategic plan, particularly in this chapter. Specific reference should be made to linked ocean and regional scale water cycle process studies.

Sixth Overview Comment

The "State of Knowledge" sections need to be enhanced. There needs to be an indication that progress has been made during the past decade. The "Research Needs" section should be closely linked to the "State of Knowledge", indicating how the new research extends and enhances the existing knowledge. At present, the sections appear discordant and somewhat disorganized.

Eighth Overview Comment

The needs to be a strong statement to emphasize research leading to a better integration of water management systems and forecasts so as to allow sufficient reaction time for climate perturbations. This research should be oriented toward determining the appropriate lead times, model resolutions, and communication structure.

References:

Betts, A.K., P. Viterbo, and E. Wood, 1998: Surface energy and water balance for the Arkansas-Red River basin from the ECMWF Reanalysis, J. Climate, 11, 2881-2897.

Betts, A.K. and P. Viterbo, 2000: Hydrological budgets and surface energy balance of seven subbasins of the Mackenzie River from the ECMWF model, J. Hydrometeorology, 1, 47-60.

Roads, J. and A. K. Betts, 2000: NCEP-NCAR and ECMWF reanalysis surface water and energy budgets for the Mississippi River basin, 1, 88-94.

Roads, J. and coauthors, 2002: GCIP water and energy budget synthesis (WEBS), submitted to JGR.

*Brian Soden*

I think this is a very difficult chapter to write because the water cycle is so broad and has so many different facets linked to climate change. Each person's comments are going to reflect their own particular sub-discipline. I agree with some of the earlier comments that the subtopics within the chapter often lack focus and require greater clarification and distinction among them. From my perspective, there are at least 4 well-defined subtopics of relevance for which I've added a few comments.

Climate Feedbacks - changes in components of the water cycle that directly influence the climate sensitivity; ie that impact the TOA radiative fluxes (clouds, water vapor, snow/ice). There are other indirect effects of the water cycle (eg. through interactions with the carbon cycle). These are certainly important and should be mentioned, but I think the distinction between direct water feedbacks and indirect ones should be made.

Water cycle changes - What is the sensitivity of the water cycle to both natural variations and externally-forced changes in climate? What processes determine this sensitivity? These questions are most naturally thought of at the global scale (ie a closed system) and are intimately linked to the radiative energy budget (ie the balance between global-mean latent heating and global-mean radiative cooling of the atmosphere). This connection between the water and energy cycles and the need for integrated assessments of the two should be more clearly articulated.

Regional manifestations - How are changes/variations in the global mean precipitation manifest at the regional (watershed) scale impacts: What are the impacts of regional variations in water variables on ecological, agricultural, economic activities?

The subject of extreme precipitation events cuts across all of these subtopics and perhaps it is best to treat it as a separate subtopic, rather than blur the lines between them.

Jim Hack:

My comments are biased by what I regard to be my large-scale perspective on this problem. Without question, there are very many important problems associated with developing a better scientific understanding of water cycle processes on the scale of watersheds or river basins. This is especially important when it comes to quantifying societal impacts. But the fact remains that more than two thirds of the Earth's surface is covered with water, where our modeling capabilities continue to be deficient with regard to quantifying important features of the water cycle on ocean basin, or even global scales. A better effort must be made to balance the discussion between regional hydrological (terrestrial) studies, primarily highly-localized process-oriented research, and large-scale research on the global water cycle (local and non-local behavior) which in effect provides the boundary conditions on regional behavior. I recognize that length constraints, and competing scientific foci, often require undesirable compromises. But there must be a much better balance between large-scale and small-scale research requirements, and a better linkage of the two extreme scales of motion to each other.

Overall, the text does a poor job of conveying the need for fairly fundamental, large-scale, research on the GLOBAL WATER CYCLE. All too often, the material is far too focused on relatively small-scale issues, more in the category of process studies and application work, ignoring the links and the need to scale up to global-scale questions. The issue of scale is a generally muddied concept in this document. The research agenda for an understanding of the global water cycle on climate time scales is quite different from the agenda for understanding the water balance in a watershed on seasonal or shorter time scales. Conceptually, this needs to be more clearly articulated. The concepts of "forcing" and "feedback" are also often confused throughout the text.

## USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP

Page 80, Chapter 7: Focus on Feedbacks and Forcing and Separate the Water Vapor and Cloud Feedbacks from Land Hydrology

As was noted in V Overview Comment: Part I, Chapter 2 and amplified in VI Omission: Part 1, Chapter 4, the water vapor and cloud feedback problems should be clearly separated from land-hydrology; otherwise, these problems will disappear among the cacophony of demands for regional studies. The water vapor and cloud-feedback problems span all scales including the global scale, and of course, they're not confined to land. I would prefer to see chapters devoted to "major forcings" and "major feedbacks" while keeping the remaining chapter. If the aim is to reduce the uncertainty in climate prediction, improved knowledge of the forcings and feedbacks will certainly help. Let Chapter 7 become land hydrology, and focus it on the problems associated with land hydrology.

## JIM COAKLEY, OREGON STATE UNIVERSITY

Page 80, Table, Question 3:
What are these "water cycle variables?" This vague terminology is used throughout the text, but never defined; even in the longer white paper. Specifically, what's important?; what can we measure?; how accurately do we need to know these things?; and on what kinds of time and space scales?. There shouldn't be uncertainty about what's required to reduce the "observational and predictive uncertainties" for these ambiguous quantities.
Jim Hack:

## USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP

Page 80, Chapter 7: The chapter is too vague. 'Water cycle processes' should be broken down into specific processes; I focus here on precipitation. It also gives the incorrect impression that we cannot believe any of the results of precipitation models. This is politically self-serving and does not reflect the state of the art.

## MARCIA BAKER, UNIVERSITY OF WASHINGTON

Page 80, Chapter 7: **First Overview Comment:** The role of water vapor, clouds and the magnitude of the water vapor feedback should be a top research priority, and we hope that this area is given sufficient resources.

## GEORGE WOLFF, PH.D., GENERAL MOTORS

Page 80, Chapter 7: Overall, this chapter puts little emphasis on regional studies of the water cycle. While it is acknowledged on Page 84, Line 3, and a few other places, it is clear that global-scale studies are emphasized. This is a weakness in this chapter since impacts of climate change, particularly with regard to water management practices, occur on scales far too small to be resolved by current or near-future GCMs. I suggest including emphases on regional climate prediction model development and on regional- and local-scale intensive field experiments.

**Second Overview Comment**: It is pointed out throughout much of this chapter that soil processes are critically important to understanding the water cycle. However, there is no mention of the need to enhance and maintain soil condition observations (particularly water content and temperature) on a national (U.S.) or, better, global scale. This research need should be explicit in the chapter.

## DAVID KRISTOVICH, ILLINOIS STATE WATER SURVEY

Page 80, Chapter 7:

- See earlier comments about the importance of the water cycle as a potential integrating theme for the USCCSP – **water is a natural integrator of climate processes AND their consequences** and this fact should be highlighted in this Chapter at least if not in/for the Strategic Plan as a whole.

- Remember the **"cascading effects" of the water cycle on a number of decisions and sectors** beyond just water resource management (e.g., health, agriculture, fisheries, tourism, transportation, etc.)

- **Lessons learned from responding to past (and current) variability** should be an important area of investigation for this Chapter (and the USCCSP as a whole). In the area of water resources in particular, **insights gained from traditional knowledge and practices** are potentially valuable (particularly in some regions).

- Look for opportunities for linkages between Chapter 7 and discussions of land use/land cover change in Chapter 8. In particular, emphasize the importance of **exploring mechanisms that address integrated water and land use management**.

- Remember that one size does not fit all and that there will be **unique factors** that enhance vulnerability or limit response options **in some regions**, most notably, **low-lying islands and coastal areas**.

- Explicitly recognize the **importance of extreme events** (e.g., droughts, floods and storminess) for water resources in some regions. See earlier comments about the possibility of considering extreme events as an integrating theme for all or part of the USCCSP.

## EILEEN L. SHEA, EAST-WEST CENTER

Page 80, Chapter 7: <u>First Overview Comment</u>: The 2003 update of the California Water Plan is utilizing the most intensive collaborative stakeholder process to date for updating the Water Plan. If the USGCRP is to better serve the stakeholders and decision makers through the use of this CCSP strategic plan, it needs to identify 1) who are the ones that specifically need the answers to the research questions and 2) identify the level of "acceptable uncertainty" needed by the decision makers in order to take a climate change response action.

<u>Second Overview Comment</u> : The Chapter should explain the need for determining the return value of research programs to specific stakeholders and decision makers. For example, some levels of research may be more useful for flood forecasting/emergency response activities while other research is more useful for activities that plan and design our future investments in growth.

Third Overview Comment: A process for periodically updating research questions is needed as stakeholders and policy makers make decisions and change directions over time. California water policy has significantly changed during its history due to changes in priorities and changes would be expected to continue in the future as it deals with population growth and demographics.

**DOUG OSUGI, CA DEPARTMENT OF WATER RESOURCES**

Page 80, Chapter 7: This chapter addresses impacts on the water cycle and suggest the consequences could be rather dramatic in relation to competition for water in agriculture and urban needs. There should be at least a few Specific Questions addressing climate change modification of regional and temporal changes on water availability and the ability of regional agricultural production to adapt.

**LOWRY A. HARPER, USDA-ARS, WATKINSVILLE, GA.**

Page 80, Chapter 7: This chapter addresses impacts on the water cycle and suggest the consequences could be rather dramatic in relation to competition for water in agriculture and urban needs. There should be at least a few Specific Questions addressing climate change modification of regional and temporal changes on water availability and the ability of regional agricultural production to adapt.

Steven R. Shafer, USDA-ARS

Page 80, Chapter 7: The first three questions presented in the chapter are relevant and important climate questions whose history dates back at least a decade. These three questions can be wrapped into two slightly more detailed questions, thereby leaving room for a third question that is timely and more focused. As it stands, the linkage between the questions on the first page and the overarching questions is weak. In addition to the changes that are suggested below, the overarching questions need to be revisited and modified as suggested in later comments.

Suggested Questions (1)-(3)

Question 1: What are the key *global-scale* uncertainties, internal mechanisms, and feedback processes of water cycle variables on seasonal to decadal time scales, and what is their level of inherent predictablity?

Question 2: How do water cycle feedback mechanisms operate *on local, regional, and river-basin scales*, and how do they feedback to other parts of the climate system (e.g. carbon, nitrogen, and energy cycles)?

Question 3: Is it possible to obtain observational closure of the atmosphere and land water and energy budgets *from river-basin to local (watershed) scales* and what are the associated uncertainties in this closure?

Question 4: How do the water cycle and its variability affect the availability and quality of water supplied for human consumption, economic activity, agriculture, and natural ecosystems: and how do its interactions and variability affect sediment and nutrient transports

**Comments on Chapter 7**

Question 4-5: unchanged

There should be a Chapter Question 6: What is the likelihood of changes in extreme event sensitivity and occurrence in space and time and what are the changes in extreme event impacts due to human modifications and water uses (consumptive withdraws and interbasin diversions)?

Second Overview Comment: Climate-driven changes in the water cycle will manifest themselves on local and regional scales, so the principal focus of water cycle research in the near future should strongly emphasize improved understanding of water cycle processes on these scales. Improved understanding of the physical processes at these scales is required for more accurate representations in coupled hydrologic models of all types. To achieve the necessary level of understanding of regional and local water cycles, it is essential to develop well-instrumented regional water cycle testbeds. These testbeds are mentioned in several places in the chapter, but they need to be highlighted and should be a central feature of the research strategy. There are plenty of models of global, regional, and local hydrologic processes, but there is no comprehensive data set from which to validate the models. The riparian (river-scale) water budget has never been balanced in any model because we lack understanding of the regional and local scale processes that contribute to the water budget (Roads et al., 1994; Betts et al., 1998; Roads and Betts, 1999; Betts et al., 1999; Roads et al., 2002). Another contributing factor may be insignificant model resolution relative to the processes that must be characterized and, in addition, our understanding of ground water and soil moisture processes is still not adequate because we have a limited set of observations. They are part of the hysteresis that exists in the climate system, so it is essential to properly understand them on a number of scales. Efforts to discuss the links between global water cycle processes and local impacts hinge on knowledge of the links between local and regional processes. While progress is possible through continued development of coupled and integrated models, such development will be of limited utility until data sets are available for more comprehensive model testing. This chapter should focus on the study of regional and local scale water cycle processes and everything else should be wrapped around this principal activity. We must have an integrated view of the river-basin water cycle, which means a comprehensive set of coordinated measurements at a variety of scales. One of the "illustrative research questions" should focus on the development and implementation of instrument systems capable of performing closure experiments from local to river-basin scales.

Third Overview Comment: The current chapter lacks focus and is inconsistent in terminology. A clear distinction needs to be made between research aimed at understanding the global hydrologic cycle, regional and local water cycle processes, and water quality. Improved understanding of the global hydrologic cycle will require significantly different research than improving regional models of water cycle processes; yet in the current chapter it seems to be folded into a single ill-defined package. The overall intent of the traditional feedback- and process-related research should be improved understanding of local and regional water cycle processes because they are closely tied to the human impacts; a clear progression of research toward this goal is required.

Fourth Overview Comment: On a more basic level, the first of the "overarching" questions emphasizes water quality, cycling of nutrients and toxic substances, and human and ecosystem health, in addition to the "traditional" climate change research emphasis on understanding the global distribution of water and water-climate feedback processes. This water-consumption-based emphasis is reinforced by the second overarching question which highlights the capacity of "societies to provide adequate supplies of *clean* water" (emphasis added). These two questions appear to signal a major change in research focus from the climatic feedback effects of water and its forms (i.e., climate change causes) to research into the "end-use" consequences of changes in the water cycle. If this change was intended, however, it was not carried forward to the chapter-leading questions, only one of which (#4) mentions water consumption issues. This apparent quandary illustrates a key problem with the linkages in the current document between the overarching questions and the questions at the beginning of the chapter.

The overarching questions should be subdivided into two major themes: climate-induced changes in water distribution and the consequences of such a redistribution. *As they currently stand, the overarching questions appear too heavily weighted toward water quality and contain redundant information.* Water quality is a complex issue because the processes that modulate it can occur on extremely small scales, and efforts to simulate water quality on climate scales are dependent on successful simulation of the water budget, which is the first order problem. References to "toxic substances" and "affects on human and ecosystem health" should be limited to the second overarching question. The following overarching questions achieve better separation of tasks:

(1) How do water cycle processes (including climate feedbacks) and human activities influence the distribution of water within the Earth System, and to what extent are changes predictable?
(2) What are the potential socioeconomic consequences of climate-induced changes in the distribution of water? How would these changes link to demographic trends, land use (including changes in agriculture and land management practices), the cycling of important chemicals (carbon, nitrogen, other nutrients, and toxic substances), and local water quality.

Fifth overview comment: for many *global and regional* studies of the water cycle to be successful, specific attention needs to be given to the role of the oceans in the water cycle, and in the partitioning of the freshwater flux to the ocean from precipitation, sea-ice melt, and continental runoff. The IPCC community has identified the Oceanic Meridional Circulation (MOC) as a particularly volatile climate process because of its large role in poleward heat transport and the propensity of coupled atmosphere-ocean models to weaken it during $CO_2$-induced warming. freshening of the high-latitude oceans is believed to be a key ingredient in the weakening of the MOC and the ensuing abrupt hemispheric climate change. there should be a strong emphasis on the world's oceans present in this strategic plan, particularly in this chapter. Specific reference should be made to linked ocean and regional scale water cycle process studies.

Sixth overview comment: the "State of Knowledge" sections need to be enhanced. There needs to be an indication that progress has been made during the past decade. The "research needs" section should be closely linked to the "State of Knowledge", indicating how the new research extends and enhances the existing knowledge. At present, the sections appear discordant and somewhat disorganized.

Eighth Overview Comment: The needs to be a strong statement to emphasize research leading to a better integration of water management systems and forecasts so as to allow sufficient reaction time for climate perturbations. This research should be oriented toward determining the appropriate lead times, model resolutions, and communication structure.

REFERENCES

Betts, A.K., P. Viterbo, and E. Wood, 1998: Surface energy and water balance for the Arkansas-Red River basin from the ECMWF Reanalysis, J. Climate, 11, 2881-2897.

Betts, A.K. and P. Viterbo, 2000: Hydrological budgets and surface energy balance of seven subbasins of the Mackenzie River from the ECMWF model, J. Hydrometeorology, 1, 47-60.

Roads, J. and A. K. Betts, 2000: NCEP-NCAR and ECMWF reanalysis surface water and energy budgets for the Mississippi River basin, 1, 88-94.

Roads, J. and coauthors, 2002: GCIP water and energy budget synthesis (WEBS), submitted to JGR.

## MILLER, ET AL., BROOKHAVEN NATIONAL LABORATORY

Page 80, Chapter 7:

1. There should be more emphasis placed on: Has and will warming result in an intensification of the global water cycle? As one comment put it "The IPCC Second Assessment Report (SAR) concluded that intensification was all but inevitable, the IPCC TAR has reduced the likelihood somewhat and recent studies are less certain still, as far as the inevitability of this climatic response. At the very least it is very likely that it will vary greatly by region. More emphasis should be placed on the study of historical records for detection of response during the 20th century and continued *in situ* monitoring for future detection.

2. There should be more emphasis placed on: How can the scientific community contribute to the quantification of "Dangerous Human Influences" associated with various concentrations of greenhouse gasses. This and other chapters do not address this question directly and I think the plan would be well served by some consideration of how this danger could be quantified. Quantification could take the form of formally defining most probable climate outcomes from selected emission scenarios. These outcomes would then be evaluated based on most probable effects on a suite of water cycle related

variables such as the availability of surface and groundwater resources, precipitation inputs for rain-fed crops and forests, salt water intrusion, sea level rise, increased or decreased risks to infrastructure, agriculture and human life from extreme events. If the quantification necessarily must involve valuation of resources at risk I would strongly suggest enlisting the support of the re-insurance community (an important stakeholder). My understanding is that this community has funded their own assessments of the risks associated with climate change and they have quantified risks in dollars.

3. There should be more emphasis placed on: How would intensification of the hydrologic cycle enhance soil erosion with resulting losses in soil organic carbon and soil degradation that would have a negative feedback in that plant residue inputs could be reduced owing to lower fertility and moisture holding capacity. Hence there is an important linkage to the carbon cycle via the effect of intensification of the hydrologic cycle on soil erosion and plant productivity.

4. There should be more emphasis placed on: How will the ongoing systematic depletion of groundwater resources be influenced by climate change and how is this process related to sea-level rise.

5. There should be more emphasis placed on: Quantify the relation between temperature, precipitation and water use? How does water use increase with increasing temperature and reducing precipitation?

6. There should be more emphasis placed on: How will the inevitable intensification of agriculture to meet the demands of a growing population (that will demand more meat products) influence demands for irrigation, thus competition for a finite resource, as climate warms.

7. There should be more emphasis placed on: How will the potential decrease in soil organic matter (caused by climate warming, intensification of agriculture, extensification of agriculture and increased rate of erosion [due to intensified hydrologic cycle]) affect the available water capacity (AWC) of soils. If AWC declines significantly this will have an undesirable effect on plant productivity and by reducing soil moisture it could have an undesirable effect on local climate.

8. There should be more emphasis placed on: How will intensification of the hydrologic cycle effect methanogenesis, methanotrophs and denitrification (soil $N_2O$ production). Methane and nitrous oxide are key greenhouse gasses that are increasing in atmospheric composition.

9. There should be more emphasis placed on: How can federal agencies better coordinate the collection, synthesis and analysis of water use data which is critical to our understanding of current and future demands on water resources. Although it is critical there is no framework in place to monitor water use in a meaningful way. There is also a critical need for monitoring the nation's groundwater resources in a systematic way both to track aquifer storage and how it may respond to climate and withdrawals.

10. There should be more emphasis placed on: How will changes in the ratio of snow to rain effect hydrologic regimes.

11. There should be more emphasis placed on: How will ongoing and future changes in hydrologic regimes such as advance in timing of Spring lake and river ice-out, spring snowmelt-dominated flow, decreases in summer and fall flow, increases in surface water temperature influence ecosystems with aquatic biota that are sensitive to these types of changes.

Additional Comments on Chapter 7 Water Cycle

1. There is a need for more background information that acknowledges the immense body of scientific work summarized by the various IPCC, National Academy of Science, and other related reports. This information should contain citations. I do not believe that it is fair to state that there is a high level of uncertainty about various aspects of climate change and the water cycle without acknowledging the many areas that the scientific community has a high degree of confidence in their overall assessment.

2. There is a need for prioritization of the critical questions and research directions. The prioritization should be based on some combination of A. scientific uncertainty that blocks progress B. cost C. ability to achieve results under the stated program time frame.

3. The plan does not address the issue of the risks associated with political instability associated with disputes over water use between nations. See Scientific American Special Report: Safeguarding Our Water/Making Every Drop Count; February 2001; by Peter H. Gleick and UL http://www.worldwater.org/conflict.htm

4. In the paragraph on the State of Knowledge I would strenuously disagree with the blanket statement that "we cannot definitively attribute observed trends in the water cycle to human-induced changes as opposed to natural variability". If one accepts the IPCC TAR synthesis that more than half of the 20th century warming is attributable to human influences (CO2 and land use change) and the body of evidence that exists supporting systematic and coherent changes in hydrologic variables that correlate with rising air temperatures (selected publications listed below), then it seems that there is sufficient evidence to state that WE CAN SAY WITH A HIGH DEGREE OF CONFIDENCE THAT THE GLOBAL WATER CYCLE HAS BEEN AFFECTED BY HUMAN-INDUCED CLIMATE CHANGE.

Brown, R.D. 2000. Northern Hemisphere snow cover variability and change. Journal of Climate 13:2339-2355.

Burn, D.H. 1994. Hydrologic Effects of Climatic Change in West-central Canada. Journal of Hydrology 160:53-70.

Cayan, D.R., M.D. Dettinger, S.A. Kammerdiener, J.M. Caprio, and D.H. Peterson. 2001. Changes in the onset of spring in the western United States. Bulletin Amer. Met. Soc. 82:399-416.

Dettinger, M.D., and D.R. Cayan. 1995. Large-scale atmospheric forcing of recent trends toward early snowmelt runoff in California. J. Climate 8:606-623.

Dettinger, M. D.; Diaz, H. F. Global characteristics of stream flow seasonality and variability. J. Hydrometeor. **2000**, *1*, 289-310.
Douglas, E.M., R.M. Vogel, and C.N. Kroll. 2000. Trends in floods and low flows in the United States: Impact of spatial correlation. Journal of Hydrology 240:90-105.
Dudley, R.W., G.A. Hodgkins, Trends in streamflow, river ice and snowpack for coastal rivers in Maine during the 20th century: U.S. Geological Survey, Water-Resources Investigations Report IN PRESS.
Gornitz, V., C. Rosenzweig, and D. Hillel. 1997. Effects of anthropogenic intervention in the land hydrologic cycle on global sea level rise. Global and Planetary Change 14:147-161.
Groisman, P.Y., and D.R. Easterling. 1994. Variability and trends of total precipitation and snowfall over the United States and Canada. J. Climate 7:184-205.
Groisman, P.Y., T.R. Karl, and K.T. W. 1994. Changes in snow cover, temperature and radiative heat balance over the northern Hemisphere. J. Climatology 7:1633-1656.
Groisman, P.Y., P.W. Knight, and T.R. Karl. 2001. Heavy precipitation and high streamflow in the United States: Trends in the 20th Century. Bulletin of the American Meteorological Association 82:219-246.
Hauer, FR; Baron, JS; Campbell, DH; Fausch, KD; Hostetler, SW; **Leavesley**, GH; Leavitt, PR; McKnight, DM; Stanford, JA, Assessment of climate change and freshwater ecosystems of the Rocky Mountains, USA and Canada,SPECIAL ISSUE: FRESHWATER ECOSYSTEMS AND CLIMATE CHANGE., JOHN WILEY & SONS, Jun 1997, pp. 903-924,
Hay, LE; Wilby, RL; **Leavesley**, GH, A comparison of delta change and downscaled GCM scenarios for three mountainous basins in the United States, [J. Am. Water Resour. Assoc.]. Vol. 36, no. 2, pp. 387-398. Apr 2000.
Hodgkins, G.A., I.C. James, and T.G. Huntington. 2002. Historical changes in lake ice-out dates as indicators of climate change in New England. Intl. J. Climatology 22:1819 - 1827.
Huntington, T. G., G. A. Hodgkins, R. W. Dudley, Historical trend in ice thickness on the Piscataquis and Saint John Rivers, Maine, Proceedings, Eastern Snow Conference, American Water Resources Association, 5-7 June 2002, Stowe Vermont. IN PRESS.
Knowles, Noah; **Cayan**, Daniel R., 2002, Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary, Geophysical Research Letters, 10.1029/2001GL014339, 28 September 2002
Leith, R., and P. Whitfield. 1998. Evidence of climate change effects on the hydrology of streams in south-central BC. Cdn. Water Resources J. 23:219-230.
Lettenmaier, D.P., E.F. Wood, and J.R. Wallis. 1994. Hydro-climatological Trends in the Continental United States 1948-1988. Journal of Climate 7:586-607.
Lettenmaier, D.P., D. Ford, S.M. Fisher, J.P. Hughes, and B. Nijssen. 1996. Water management implications of global warming, 4:The Columbia River Basin. Report to Interstate Commission on the Potaomac River Basin and Institute for Water Resources, U.S. Army Corps of Engineers, Univ. of Wahsington, Seattle Washington.
Lettenmaier, D.P., A.W. Wood, R.N. Palmer, E.F. Wood, and E.Z. Stakhiv. 1999. Water resources implications of global warming: a U.S. regional perspective. Climatic Change 43:537-579.

Lins, H.F., and P.J. Michaels. 1994. Increasing U.S. Streamflow Linked to Greenhouse Forcing. EOS, Transactions, American Geophysical Union 75:284-285.

Lins, H.F., and J.R. Slack. 1999. Streamflow trends in the United States. Geophys. Res. Letters 26:227-230.

Livingstone, D.M. 1997. Break-up dates of alpine lakes as proxy data for local and regional mean srface air temperatures. Climatic Change 37:407-439.

Magnuson, J.H., D.M. Robertson, B.J. Benson, R.H. Wynne, D.M. Livingstone, T. Arai, R.A. Assel, R.G. Barry, V. Card, E. Kuusisto, N.G. Granin, T.D. Prowse, K.M. Stewart, and V.G. Vuglinski. 2000. Historical Trends in Lake and River Ice Cover in the Northern Hemisphere. Science 289:1743-1746.

McCabe, G.J., and M.A. Ayers. 1989. Hydrologic effects of climate Change in the Delawaer River basin. Water Resour. Bull. 25:1231-1242.

McCabe, G.J., and D.M. Wolock. 2001. Trends in temperature sensitivity of moisture conditions in the conterminous United Sates. IN PRESS.

Milly, P.C.D., and K.A. Dunne. 2001. Trends in evaporation and surface cooling in the Mississippi River basin. Geophysical Research Letters 28:1219-1222.

Milly, P.C.D., R.T. Wetherald, K.A. Dunne, and T.L. Delworth. 2002. Increasing risk of great floods in a changing climate. Nature 415:514-517.

Mitrovica, J.X., M.E. Tamisiea, J.L. Davis, and G.A. Milne. 2001. Recent mass balance of polar ice sheets inferred from patterns of global sea-level change. Nature 409:1026 - 1029.

Poff, N.L. 1992. Regional Hydrologic Response to Climate Change - An Ecological Perspective, p. 88-115, *In* P. Firth and S. G. Fisher, eds. Global Climate Change and Freshwater Ecosystems. Springer-Verlag, New York.

Poff, N.L., M.M. Brinson, and J.R. Day. 2002. Aquatic ecosystems and global climate change: Potential impacts on inland freshwater and coastal wetland resources in the US. Pew Center on global climate change, WWW electronic pub.

Prowse, T.D., and M. Conly. 1998. Impacts of climatic variability and flow regulation on ice-jam flooding of a northern delta. Hydrologic Processes 12:1589-1610.

Sahagian, D.L., F.W. Schwartz, and D.K. Jacobs. 1994. Direct anthropogenic contributions to sea level rise in the twentieth century. Nature 367:54-57.

Schindler, D.W. 2001. The cumulative effects of climate warming and other stresses on Canadian freshwaters in the new millenium. Can. J. Fish. Aauat. Sci. 58:18-29.

Soldatova, I.I. 1993. Secular variations in river breakup dates and theis relationship with climate variations. Soviet Meterology and Hydrology (In Russian) 9:89-96.

Trenberth, K.E. 1999. Conceptual Framework for Changes of Extremes of the Hydrological Cycle with Climate Change. Climatic Change 42:327-339.

Vinnikov, K.Y., A. Robock, R.J. Stouffer, J.E. Walsh, C.L. Parkinson, D.J. Cavalieri, J.F.B. Mitchell, D. Garrett, and V.F. Zakharov. 1999. Global warming and northern hemisphere sea ice extent. Science 286:1934-1937.

Vörösmarty, C.J., and D. Sahagian. 2000. Anthropogenic disturbance of the terrestrial water cycle. BioScience 50: 753-765.

Vörösmarty, C.J., C. Li, J. Sun, and Z. Dai. 1998. Emerging impacts of anthropogenic change on global river systems: The Chinese example, p. 210-244, *In* J. Galloway and J. Melillo, eds. Asian Change in the Context of Global Change: Impacts of Natural and

Anthropogenic Changes in Asia on Global Biogeochemical Cycles. Cambridge University Press.
Waggoner, P.E. 1990. Climate Change and U.S. Water Resources John Wiley and Sons, New York.

5. Support and enhance the infrastructure for in situ monitoring of surface and ground water resources. This data is of fundamental importance for understanding ongoing trends, model calibration for future prediction, water resource management.

6. The plan does not mention desertification that is an important water cycle problem that is a crosscutting issue linked to the carbon cycle, land use change, and ecosystems.

7. The plan does not mention the fact that empirical analyses such as space-for-time substitutions could be a useful research direction as an adjunct to modeling to predict future effects of climate warming on water resources. For example, in the eastern US on average, water yield varies by a factor of two between Georgia and Maine while mean annual temperature varies by 10 to 12 ˚C.

8. There is a general lack of correspondence between the overarching questions posed by the chapter on the one hand and the "Products and payoffs". The Products and payoffs are all model output oriented and yet many of the questions are baed more on refinement of our understanding of process and I suggest the products be written in the same way.

9. The global water cycle chapter cannot do everything and one area that think could be de-emphasized is in the area of contaminant and nutrient transport. These are important issues, but could be dealt with in other programs.

10. There is little to no mention of reservoirs and their significance in the global water cycle and the effect that climate change may have on them. One interesting problem is the fact that in areas where warming may shift the timing of snowmelt into earlier spring/late winter when reservoir managers are in "flood control mode" they may be forced to dump the water to maintain capacity and later when they can build capacity again there will be less water available.

## THOMAS G. HUNTINGTON, U.S. GEOLOGICAL SURVEY

Page 80, Chapter 7: The Water Cycle **CANNOT** be considered separately from the Energy Cycle – the text on page 83, lines 23-24 has it right. However, the whole plan and much of this chapter are written as if the water cycle can be considered separately. There are important reasons to focus more on Water Supply because this has more direct relevance to the effects of climate change on the biosphere (including humans), but progress on understanding the factors affecting Water Supply cannot logically occur if we do not adequately understand the Water Cycle and the Water Cycle is just a part of the Energy Cycle.

## WILLIAM B. ROSSOW, NASA GODDARD INSTITUTE FOR SPACE STUDIES

## Comments on Chapter 7

Page 80, Chapter 7: Much of this is a repackaging of GEWEX.
Question 3 is redundant with much of Chapter 6.

**ANTONIO J. BUSALACCHI, EARTH SYSTEM SCIENCE INTERDISCIPLINARY CENTER (ESSIC), U. MARYLAND**

Page 80, Chapter 7: The emphasis of the chapter on the interactions of the water cycle with other cycles, e.g, carbon, is very good. This will have to be addressed as part of any climate change scenario assessment.

The discussion of the water cycle is quite complete. To increase the value of evaluating the water cycle there needs to be a mention of the spatial and temporal scales of interest because of the role that managed agricultural systems have on the water balance. The role of evapotranspiration needs to be discussed rather than inferred in this chapter.

**JERRY L. HATFIELD, USDA-ARS NATIONAL SOIL TILTH LABORATORY**

Page 80, line 6: It is suggested that evapotranspiration (or evaporation and transpiration) be included after precipitation.

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 80, Line 6: Include sea level rise in this list

**LARA HANSEN, WORLD WILDLIFE FUND**

Page 80, line 11: . . .inadequate understanding of, and inability to model. .' .is far too sweeping and negative. Criteria for distinguishing 'successful' from 'unsuccessful' models are needed to make any statement on this subject sensible. Such criteria have been discussed in previous documents (IPCC TAR, National Climate Assessment (2000), papers in the literature) that, inexplicably, this document doesn't cite. Our skill in modelling continental precipitation on the mesoscale, for example, is fairly high (with seasonal precipitation errors on the order of 10% or better in most cases), whereas over marine areas it is lower and on convective scales often more accurate. Also, the time scale of the models determines the skill.

**MARCIA BAKER, UNIVERSITY OF WASHINGTON**

Page 80, line 11: IPCC puts out assessment reports, not just reports.

**MICHAEL MACCRACKEN, LLNL (RETIRED)**

Page 80, line 11: It is improper to say that we have an "inability to model"—we may have a limited ability, but not an inability to do it.

**MICHAEL MACCRACKEN, LLNL (RETIRED)**

Page 80, line 12: Convoluted sentence. It also confuses forcing and feedback, a problem throughout this section. How about "In particular, clouds, precipitation, and water vapor produce forcings on the climate system that alter surface and atmospheric heating rates.

Redistribution of the associated heat sources and sinks lead to poorly understood feedbacks in the form of adjustments to atmospheric and oceanic circulation patterns and the associated distribution of precipitation." Jim Hack:

**USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page. 81. Again, the Hornberger reference is misplaced here. It could be referred to among other documents as a reference, but should not be embedded in the text since this implies complete transfer to the present document without the same review process.

**SUSAN SOLOMON, NOAA**

Page 81, lines 19-20: I think I would use the word "forecasts" here rather than "predictions"—see MacCracken (Climatic Change, 2002) for a bit of discussion on this.

**MICHAEL MACCRACKEN, LLNL (RETIRED)**

Page 81, line 29:
Both of these questions are VERY applied in scope and content. Where do questions about the fundamental physics come into play? Are there fundamental questions about the processes at work that are pacing our ability to answer the broader questions on human impacts? More on this later. Jim Hack:

**USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 81; line 34: insert
What are the underlying physical, chemical, thermodynamic, and kinetic properties that govern the partitioning of these species among soil, water, and atmospheric phases?

**NIST**

Page 81, near bottom, line 38: Add "and food" after water.

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 82, "Illlustrative Research Questions": This section seems to assume that we can identify changes in the water cycle, when, in fact, we can,t even close the water budgets for basins or for the globe. This is a fundamental research question that should be addressed by the plan(s).

**DIAN SEIDEL, NOAA AIR RESOURCES LABORATORY (R/ARL)**

Page 82, lines 2-9. This is not global. Where is the role of the oceans?

**ANTONIO J. BUSALACCHI, EARTH SYSTEM SCIENCE INTERDISCIPLINARY CENTER (ESSIC), U. MARYLAND**

Page 82, Lines 3: The statement that notable changes in water variables have been observed seems rather mundane. Of course, we all know that there are daily and annual changes in these variables, as well as on longer time-scales. Suggest adding a time-scale of relevance to the global water cycle.

**DAVID KRISTOVICH, ILLINOIS STATE WATER SURVEY**

Page 82, line 3ff: This is hardly a satisfactory review of the state of knowledge, not really even explaining what the global water cycle is. It is incumbent on the plan to reference the most authoritative overviews on the subject so there is a basis for understanding where understanding is and what is planned.

**MICHAEL MACCRACKEN, LLNL (RETIRED)**

Page 82, line 5: I question whether there has been observable changes in atmospheric water vapor. High variations in many of these parameters from time to time make it difficult to detect trends. I do agree with the thrust that better measurements and sensors are needed, and also the final sentence in lines 8 and 9.

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 82, lines 7-8: The statement “cannot properly simulate the global water cycle” is really useless unless some indication is given of the extent of the differences, etc. It would be better to say “cannot simulate the global water cycle with sufficient accuracy to be able to do _____”. Vague statements here are really not helpful.

**MICHAEL MACCRACKEN, LLNL (RETIRED)**

Pgae 82, Line 8: add at end of ìcycleî, ì, although significant advances have been made in modeling moderately sized watersheds.

**BONTA**

Page 82 line 8. Again '. . .cannot properly simulate. . .' has no real meaning without definition of 'properly', and without focus on particular elements of the water cycle.

**MARCIA BAKER, UNIVERSITY OF WASHINGTON**

Page 82, Line 9: **Add sentence to end of paragraph**:
“Well dated and replicated paleoclimate data indicate the recurrence of multidecade “megadroughts” in the western US over the past 1000 years that have no counterparts in the $20^{th}$ century and whose forcing and mechanisms remain uncertain.”

**U.S. CLIVAR SCIENTIFIC STEERING COMMITTEE.**

Page 82, line 13 or somewhere in this paragraph: Analysis of the past centuries can also shed some light on natural variablility.

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 82, line 13: The word “or” is incorrect—each has likely played its part. This is not an either-or matter.

**MICHAEL MACCRACKEN, LLNL (RETIRED)**

Page 82, Lines 16-18: Preliminary results of research sponsored by the Commission suggest that groundwater may be an important adaptation tool to changes in precipitation levels and increased variability in the timing and form of precipitation in the state. However, our capabilities to model groundwater resources are hampered by the lack of a good understanding of the processes and soil and geological characteristics that determine the flow of water between groundwater reservoirs and surface sources of water. We suggest more research on this topic.

**-CALIFORNIA ENERGY COMMISSION**

Pge 82, Line 18: Insert a new bullet after this bullet: How is agricultural production changed by global precipitation patterns, including pathogens, insects, erosion, and water quality?

**BONTA**

Page 82, Lines 22-32: It seems odd that there are no model-development research needs in this section. Model-development research needs should be added.

**DAVID KRISTOVICH, ILLINOIS STATE WATER SURVEY**

Page 82, Line 22: Page 82, Research needs. Distinctions should be drawn between marine and continental atmospheres (our data from marine atmospheres is very sparse) and between the lower and the upper troposphere. The specific inclusion of possibilities inherent in auxiliary data (such as lightning) to constrain precipitation rates (line 29) is very important.

**MARCIA BAKER, UNIVERSITY OF WASHINGTON**

Page 82 line 23-32 ocean not mentioned, salinity changes might be the best way to check for changes in the (fresh) water cycle.

**MARTIN VISBECK, COLUMBIA UNIVERSITY**

Page 82, Line 25, make following change:
variables such as soil moisture. Existing in situ networks need to be maintained and enhanced, kept calibrated against national and international standards, and data sets….

**NIST, HRATCH SEMERJIAN**

Page 82, line 28: Why are river deltas added here? Is it because of anticipated sea level rise that deltas are regarded as critical?

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 82, Line 32: **Add sentence to paragraph**:
"To study longer-term variability in water availability, and in particular the recurrence of persistent drought, the network of well-dated drought-sensitive paleoclimate records needs to be expanded."

## U.S. CLIVAR SCIENTIFIC STEERING COMMITTEE.

Page 82 Line 34 to Page 83, Line 6: Human activities are emphasized in Question 1. For consistency, a payoff related to human activities should be included.

## DAVID KRISTOVICH, ILLINOIS STATE WATER SURVEY

Page 83, Lines 1-6**:** “critical water cycle variables” need to be identified, and echoed in Chapter 12 under observational priorities. In particular, subsurface variables including soil moisture and temperature profiles down to the water table (or down to bedrock) should be included. Further, the “regional” test beds should be better defined in terms of scale, and include the concept of water cycle and related observations from bedrock to the tropopause, building on existing networks/research watersheds when possible. Christa Peters-Lidard,

## USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP

Page 83, line 4: I do not believe that the time scale for significantly improving our parameterization techniques, based on process studies, needs to be so long (5-15 yrs). There are many activities ostensibly designed to ask and answer fundamental process questions, not withstanding important holes in what's being measured (e.g., closing the water budget on some scale). Even with imperfections in these programs, there are missed (therefore immediate) opportunities with regard to improving our parameterized treatments of major processes in the water cycle. Jim Hack:

## USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP

Page 83, Line 6: **Add bullet**:

• Drought reconstructions from the western US and other key regions that span the Holocene at ~decadal resolution. (2-5 years).

## U.S. CLIVAR SCIENTIFIC STEERING COMMITTEE.

Page 83, line 10: The statement that "when temperatures warm, the atmosphere will hold more water" are unnecessary oversimplifications. If one holds the relative humidity constant then, yes, the atmosphere will moisten, the process responsible for a major water vapor feedback mechanism with regard to clear-sky radiative heating. These kinds of statements should be clarified, or at least qualified. Jim Hack:

## USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP

Page 83, Line 10: Sentence should conclude, “…more moisture and there will be thermal expansion of the oceans.”

## LARA HANSEN, WORLD WILDLIFE FUND

Page 83, line 10: **(32-ES )** This is a fine point and may be worth ignoring – it’s a sort of fuddy-duddy comment from a meteorologist. It’s not really proper to say that warm air can “hold” more water vapor than cooler air (this is discussed eloquently by Craig Boren at Penn State). You can finesse this by rewording the first sentence as:

> As global temperatures warm, the amount of water vapor in the atmosphere is likely to increase.

**HP HANSON, LANL**

Page 83, line 13: This is not really the definition of parameterizations—and in any case it sounds pejorative when it will turn out to be necessary for any conceivable model.

**MICHAEL MACCRACKEN, LLNL (RETIRED)**

Page 83, line 15: Again, this type of vague use of judgmental words ("rudimentary at best") is inappropriate. Indicate how well or poorly something can be done. Whether this is adequate or not will depend on the use to which the data may be put. In addition, no one simply works with a model result—interpretations are made using an array of information, statistics, etc. how good must the information be for what purpose, and how inadequate is it—be more specific and nuanced.

**MICHAEL MACCRACKEN, LLNL (RETIRED)**

Page 83, Lines 16-20: Feedback processes related to clouds are a major problem that needs to be addressed. However, it is not the only one. This part would be stronger if it was written as cloud processes are an EXAMPLE of a feedback process … rather than as the only one.

**DAVID KRISTOVICH, ILLINOIS STATE WATER SURVEY**

Page 83, line 23: This is, in my opinion, one of the most central and fundamental questions facing climate simulation in that it is a major factor in determining climate sensitivity. The relationship of water cycle science to climate sensitivity is remarkably absent from the present text, yet the answer to this climate sensitivity question is strongly-related to our understanding of the global hydrological cycle. The climate sensitivity issue is discussed elsewhere in the document, where the water cycle chapter misses the opportunity to establish links. Jim Hack

**USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 83, lines 23 and 24: I presume this would be for current feedback, as opposed to that built into GCMs for future scenarios. Maybe the word existing should be added ahead of "net" in line 23.

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES**

Page 83, line 23: What is meant by "net water vapor-cloud-radiation-climate feedback effect"? My question is regarding the "net" and whether it means average, and if so, over what, and if not, how can all those other feedbacks be combined in a "net" sense other than globally, as opposed to varying "with latitude and season".

**DIAN SEIDEL, NOAA AIR RESOURCES LABORATORY (R/ARL)**

Page 83, lines 23-24: This is part of the climate element of the program as well. Presumably this will be coordinated. Similarly for lines 36-38.

**MICHAEL MACCRACKEN, LLNL (RETIRED)**

Page 83, lines 23 & 24: I presume this would be for current feedback, as opposed to that built into GCMs for future scenarios. Maybe the word existing should be added ahead of "net" in line 23. Maurice Roos

**USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 83, lines 25 and 26: A related question would be what a colder stratosphere woulddo, especially on the growth of thunderstorms. This question might better be a separate entry.

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 83, Lines 30-31: great to see oceans listed here

**LARA HANSEN, WORLD WILDLIFE FUND**

Page 83, line 36: Here's a great example of an opportunity to link directly to issues related to climate variability. The basic thrust, as I read it, is a general question of modes of variability, including the question of how extreme events (i.e., the statistical PDF) might change. A good start here would be to evaluate how well models predict extreme events now, and to understand why they're so poor in this regard. This is a good place to link to the climate variability issues. Jim Hack

**USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 83, line 38: insert a new bullet

What is the relationship among permafrost degradation and hydrologic processes and what are the subsequent impacts to oceanic circulation and to climate and ecosystem dynamics?

**WELLER, ET AL, UNIVERSITY OF ALASKA FAIRBANKS**

Page 84: RESEARCH NEEDS

Something that is missing in the discussion of observational techniques is the potential value of isotopic studies (deuterium and 18-O) in unraveling the hydrological cycle and sources of tropospheric water vapor. Limited studies of this sort have been done, but development of an aircraft-based spectroscopic instrument for isotopic studies of tropospheric water vapor would yield pure gold, as would modelling studies aimed at using such data to test processes.

**RAYMOND PIERREHUMBERT, THE UNIVERSITY OF CHICAGO**

Page 84, Research Needs The emphasis is exclusivelywq on modelling and parameterizing radiative properties of clouds. In situ monitoring and focussed field projects as well as remote sensing are crucial for progress.

**MARCIA BAKER, UNIVERSITY OF WASHINGTON**

Page 84, line 14:

What is a parameterization for water vapor? Water vapor is an explicitly predicted variable in global and regional models. The processes affecting the subgrid-scale redistibution of water, the transformations of water (phase change), and the source and sink terms at the Earth's surface are parameterized. But water vapor is NOT parameterized. Jim Hack

**USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 84, Line 15: The cloud-resolving models need evaluated too.

**RONALD STOUFFER, GFDL/NOAA**

Page 84, line 17: This is a completely vacuous statement. It doesn't say what we want in these datasets (what water cycle variables?) or what time and space scales need to be given special attention. More later. Jim Hack

**USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 84, after line 20: Another question would be studies of feedback from land back to the ocean, if significant, on the west coast of the USA, since most models show more heating on land than water. Will this differential increase and, if so, change weather and precipitation patterns and how far inland will the marine influence be dominant and in which seasons?

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 84, Line 20: new bullet: New tools for evaluating impacts of climate change on agricultural production, erosion, and water quality.

**BONTA**

Page 84, lines 21-23: This needs some elaboration, and coordination with other sections.

**MICHAEL MACCRACKEN, LLNL (RETIRED)**

Page 84, line 21:
Once again, a weak attempt to link to other areas. In this case the link to biogeochemical cycles is weakly articulated from a science point of view. Why are these links important? Jim Hack

**USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 84, line 27: It is nice that there is al last acknowledgement that models have at least limited skill. In any case, again, I would suggest that the word “predicting” should be changed to “forecasting” as I think the skill is at relatively short intervals.

**MICHAEL MACCRACKEN, LLNL (RETIRED)**

Page 84, Line 28-29: "One of the most critical deficiencies in climate change projections" - How is this evaluated? What metric is used?

**RONALD STOUFFER, GFDL/NOAA**

Page 84, line 32: Setting a goal of being “fully quantified” is a red herring—this can never be done.

## MICHAEL MACCRACKEN, LLNL (RETIRED)

Page 84, line 31: Really, one can try to quantify the accuracy of something—and this is what people want to know. Quantifying uncertainty is very hard, as we don't know all possible situations.

## MICHAEL MACCRACKEN, LLNL (RETIRED)

Page 85: This is a very good set of questions on the water cycle, and I thank the authors for their recognition of the importance of soil moisture. I would add that there is a bad gap between field-scale studies and regional hydrology, with inadequate research support. This hinders water transfers and other adaptations to current shortages, and will only be more of a problem in the future with increased pressure for transfers.

## WIENER, INDIVIDUAL COMMENTATOR

Page 85, Lines 10-12**:** revise the bullet.
To what extent will the seasonality, intensity, and variability of high latitude freshwater fluxes (evapotranspiration, runoff) and stores (soil moisture, permafrost) change as a result of climate warming, specifically in large basins covering a range of climatic regions.

## WELLER, ET AL, UNIVERSITY OF ALASKA FAIRBANKS

Page 85, Line 11: Suggest adding precipitation fluxes (in the parentheses after high latitude freshwater fluxes), since that is a primary link between the surface and atmospheric water cycle processes.

## DAVID KRISTOVICH, ILLINOIS STATE WATER SURVEY

Page 85, line 11: Probably a typo in middle—should be storage, I think.

**Maurice Roos, State of California Department of Water Resources**
**Also submitted for USGCRP Global Water Cycle Science Steering Group**

Page 85, line 12: Change "climate warming" to "climate warming or climate cooling".

## CLAIRE L. PARKINSON, NASA GODDARD SPACE FLIGHT CENTER

Page 85, line 14: As a comment, water managers are usually well acquainted with weather and runoff uncertaintly. What is needed, I believe, is to translate the products of the climate models into likely effects, or range of effects, at the watershed level, particularly on stream runoff.

**Maurice Roos, State of California Department of Water Resources**

## ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP

Page 85, line 22 or thereabouts: I'd add floods to the list or add the generation of flood events.

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 85, Line 22: add after soils, ìagricultural productionî

**BONTA, USDA**

Page 85, line 26 Research Needs:
Add: The great Siberian rivers occupy a unique role in the global water cycle and research on changes of the discharge of these rivers should be mentioned since this influences the stability of the Arctic Ocean, ice production and export, salinity anomalies and hence global climate.

**WELLER, ET AL, UNIVERSITY OF ALASKA FAIRBANKS**

Page 85, lines 28-30: This writer doesn't believe the item in the first bullet is that important, in view of existing seasonal runoff forecasting practice. If one could significantly improve long range precipitation forecasts, progress could be made, but that is probably well beyond a 5 year horizon. One thing to note is that there is not any standard of drought determination; different regions have different needs and differing criteria. We use a simple approach just looking at reservoir storage for the time of year and actual or forecasted seasonal river runoff. This appears to be quite adequate for general purposes.

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 85, line 28: This is another case, symptomatic of a broader problem, where the various scales of motion, and the difference between basic research and application (e.g., monitoring), continue to be muddied. <u>Jim Hack</u>

**USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 86, line 6: Again, the use of the word "rudimentary"—need to rephrase to say that it is inadequate in order to do something or other. Get away from such blanket terms.

**MICHAEL MACCRACKEN, LLNL (RETIRED)**

Page 86, line 10: It is suggested that wetlands be added after agriculture.

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 86, Line 10: add after agriculture, ì(crops, animals, insects, diseases)î

**BONTA, USDA**

Page 86, line 10: Recommend adding inland shipping to the list of uses affected by variations in water availability.

**DEPARTMENT OF TRANSPORTATION, LAWSON**

Page 86, lines 17-19: Isn't a lot of this already available?

**ANN FISHER, PENN STATE UNIVERSITY**

Page 86, line 20: Recommend adding water quantity to the third illustrative question.

**DEPARTMENT OF TRANSPORTATION, LAWSON**

Page 86, Line 28, Add sentence that says "The scarcity and increasing cost (value) of providing water will be exacerbated by climate change and that more accurate operational models simulating runoff, storage and conveyance systems will be needed to identify resiliency and flexibility of existing systems."

**DOUG OSUGI, CA DEPARTMENT OF WATER RESOURCES**

Page 86, Line 30: add after plumes: Furthermore, experimental watersheds are needed to develop an understanding of these processes.

**BONTA, USDA**

Page 87: Thanks! This is also a good set of questions.

**WIENER, INDIVIDUAL COMMENTATOR**

Pages 87-88, Chapter 7, we strongly support the statements made under question 5 and the goal of using climate and water cycle research and forecasts for improving policy decisions and water resource management.

**PHILIP MOTE ON BEHALF OF THE CLIMATE IMPACTS GROUP, UNIVERSITY OF WASHINGTON**

Page 87, Line 8: How deep are subsurface waters?

**RONALD STOUFFER, GFDL/NOAA**

Page 87, Line 8 The water cycle chapter should address both ground waters and surface waters; the current emphasis is on surface waters. Less is known about the response of ground waters to climate variability/change, in part because in broad areas of at least the western U.S. groundwater recharge rates over appropriate time scales are not known. Groundwater extraction rates are generally know for cities, but very poorly known for many rural/agricultural areas. With wide areas of the Western U.S. depending on groundwater, we clearly need to develop a better knowledge base for decision making.

**ROGER C. BALES, UNIVERSITY OF ARIZONA**

Page 87, Line 16, Add a sentence that says "Climate change hydrology will require engineers to look at hydrology that may not be consistent with past historical hydrological records for planning and designing long-life projects."

**DOUG OSUGI, CA DEPARTMENT OF WATER RESOURCES**

Page 87, line 17: Recommend adding inland shipping to the list of constraints on water management.

## DEPARTMENT OF TRANSPORTATION, LAWSON

Page 87, line 18: **(33-SP)** One of the “other things” that’s probably worth putting in this list explicitly is water law. Line 18 can easily read:

...regulations, complex and sometimes conflicting water law, hydropower production schedules, and increasing irrigation, urban, industrial, and recreational demands...

## HP HANSON, LANL

Page 87, Line 37: ... the planning and design of water resources infrastructure for agricultural use, recreation, and urban needs ...

## LOWRY A. HARPER, USDA-ARS, WATKINSVILLE, GA.

Page 87, Line 37: ... the planning and design of water resources infrastructure for agricultural use, recreation, and urban needs ...

## STEVEN R. SHAFER, USDA-ARS

Page 88, lines 1-11: Are these questions meant to apply to the situation around the world, or just here in the US? If the former, it is a pretty audacious effort, and may infringe sovereignty.

## MICHAEL MACCRACKEN, LLNL (RETIRED)

Page 88, line 2: **(34-E)** If you’re going to use “riparian” [with or without the explanation], you ought to be consistent and use “estuarine”.

## HP HANSON, LANL

Page 88, lines 4 and 5: For water short areas, it is hard to see that more research information will help manage demands; it becomes a legal thing, I think, to divide up the supply that is there.

## MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP

Page 88, Line 6 Most of this chapter deals with the supply side of water, with very little attention to the demand side. The key to sustainable water resources is to have a balance between supply and demand, at appropriate time scales, across a basin. The illustrative research question on ìÖ current patterns of water consumption Öî should be broadened to encompass a more detailed understanding of the amount and nature of water demand within different ecological/climatic regions and across different sectors.

## ROGER C. BALES, UNIVERSITY OF ARIZONA

Page 88, Line 8: new bullet: What are the gaps in current understanding of climate change effects on agriculture, including pathogens, insects, water quality, and water supply at a scale small enough to manage.

## BONTA, USDA

Page 88, lines 8: A desirable bit of research, I believe, would be to carefully measure current evapotranspiration with grass lysimeters, or similar tools, to see if we can determine any changes due to the increase in atmospheric carbon dioxide compared to water consumption measurements about 30 to 40 years ago. This point could be a new bullet; adding it to the item above in lines 6-8 may dilute the future thrust of that bullet item.

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 88, lines 9-11: I would like to see you add "new physical water facilities" to thelist.

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 88, Line 11, Add to end of sentence "and different levels of climate change impact uncertainties".

**DOUG OSUGI, CA DEPARTMENT OF WATER RESOURCES**

Page 88, lines 29-31: Unless we get a striking breakthrough in long range weather forecasting accuracy, particularly for precipitation, I don't think there is high potential in this item. Costs of developing and providing data input for such models may be high. It would be much better to add "initiation of some pilot studies or models" under the 3rd bullet, lines 35-38, and show a 2 to 15 year timeline.

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 88, lines 39-41: These are quite well known already by knowledgeable folks in the regions; it is difficult to see much benefit from better models to solve a deficit problem that is known.

**MAURICE ROOS, STATE OF CALIFORNIA DEPARTMENT OF WATER RESOURCES. ALSO SUBMITTED FOR USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 88, line 39: Recommend that model of water demand include minimum in stream flows necessary for ecosystem function, national/international agreements, and shipping interests.

**DEPARTMENT OF TRANSPORTATION, LAWSON**

Page 89: Water section linkages (page 89) why no link to GOOS? How can the biggest reservoir of water not be part of the water cycle?

**MARTIN VISBECK, COLUMBIA UNIVERSITY**

## Comments on Chapter 7

Page 89: Many of the "key linkages" are articulated in this section, but many are missing or inadequately identified. For example, the linkages to the Climate Variability and Change component only discusses modes of water cycle variability arising from sea surface temperature variability. It ignores very important and regular modes of natural variabilty such as the diurnal cycle (process oriented), intraseasonal tropical variability, and the seasonal cycle. It is only by studying modes of natural variability, including ENSO variability, that we stand any chance of identifying the true climate sensitivity of the Earth's climate system. There are important global observational opportunities here (e.g., via NASA's A-train plans; GPM, etc.) that may help tie down the physics associated with some of the lower frequency modes of variability.

Given the short time scale we're working with, perhaps the most effective thing to do, in addition to a critique of the CCRI document, is to work with the comments furnished to the committee by Mark. There are many worthwhile issues raised in these comments. However, once again, I feel this response focuses far too much on "small-scale" issues.

Question 1: What are the key global-scale uncertainties, internal mechanisms, and feedback processes of water cycle variables on seasonal to decadal time scales, and what is their level of inherent predictablity?

No problem, but the time scales should include diurnal through decadal time scales. How about "What are the key uncertainties, internal mechanisms, and feedback processes of the global water cycle on diurnal to decadal time scales, and what is their level of inherent predictablity?"

Question 2: How do water cycle feedback mechanisms operate on local, regional, and river-basin scales, and how do they feedback to other parts of the climate system (e.g. carbon, nitrogen, and energy cycles)?

This is "land-centric" and should include ocean basin scales of motion. Ocean biogeochemistry is comparably important to terrestrial biogeochemistry. How about "How do water cycle feedback mechanisms operate on local, regional, river-basin, continental, and ocean-basin scales, and how do they feedback to other parts of the climate system (e.g. carbon, nitrogen, and energy cycles)?

Question 3: Is it possible to obtain observational closure of the atmosphere and land water and energy budgets from river-basin to local (watershed) scales and what are the associated uncertainties in this closure?

This is a good question, but once again has a land hydrology focus. It's important to close the water budget in a general sense, and opportunities to do this over oceanic domains are as important if not more important. How about "Is it possible to obtain observational closure of the atmosphere and surface water and energy budgets from watershed to continental or ocean-basin scales and what are the associated uncertainties in this closure?"

## Comments on Chapter 7

Question 4: How do the water cycle and its variability affect the availability and quality of water supplied for human consumption, economic activity, agriculture, and natural ecosystems: and how do its interactions and variability affect sediment and nutrient transports

I wholeheartedly agree. The comparable question in the CCRP document is too detailed, and too focused on specific aspects of water quality. This formulation still covers issues of interest to agencies like EPA.

There should be a Chapter Question 6: What is the likelihood of changes in extreme event sensitivity and occurrence in space and time and what are the changes in extreme event impacts due to human modifications and water uses (consumptive withdraws and interbasin diversions)?

I feel this is an important issue, especially to the impacts community. But, in my opinion, the near-term issues are whether models operating on any spatial scale are capable of realistically representing the statistics of extreme events. I believe the answer will be they don't do a good job, which raises another basic research question: why not??

With regard to Mark's second overview comment: this is once again too focused on small-scale terrestrial water cycle questions. Answers to these questions are clearly important, but the context of watershed or regional scale process studies are explicitly dependent upon the boundary conditions determined by larger scale processes. My comments are not intended to discount the importance of regional hydrological process studies, but to seek balance in the discussion.

I generally agree with the remainder of the overview comments.

Finally, some specific suggestions about rewording portions of the CCRI draft. I raised concerns about the absence of a basic research agenda on Page 81, line 29. I completely agree that Mark's proposed rewording is a much better start:
“How do water cycle processes (including climate feedbacks) and human activities influence the distribution of water within the Earth System, and to what extent are changes predictable?”

The second sentence in the original draft is application oriented. The proposed rewording leaves the door open for someone to articulate the need for basic scientific research, which will "enable" the end-user applications.

I also feel that generic references to water cycle variables is unnecessary (e.g., page 84, line 17). What kinds of variables do we need to measure (e.g., cloud water, water vapor, cloud ice, groundwater, soil moisture, permafrost, surface water, ...)? Can they be measured with any degree of accuracy? On what scales?

## Comments on Chapter 7

This is all I can do for now. I would have preferred to provide more in the way of suggested re-writes, but it's probably more important to get some comments filed. I hope it's of some help. I've copied a few others as an FYI. Jim Hack

**USGCRP GLOBAL WATER CYCLE SCIENCE STEERING GROUP**

Page 89, line 6: **(35-E)** “ocean sea surface temperatures” is a typo – “ocean” or “sea”, not both.

**HP HANSON, LANL**

Page 89 line 28.: **(36-E)** More fuddy-duddy-ness: “such as Japan” would be preferable to “like”.

**HP HANSON, LANL**

Page 89, line 32: Having only one reference here is really an indication that the State of Knowledge summaries are very limited. There is much more than just this report meriting citation (Like IPCC, GEWEX, CLIVAR and NRC reports).

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