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ITEM 4

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
Colorado State Office
2850 Youngfield Street
Lakewood, Colorado 80215-7210
www.co.blm.gov

In Reply Refer To:
7250 (CO-932)

FEB 1 9 2015

Ms. Rebecca Mitchell
Chief, Water Supply Planning Section
Colorado Water Conservation Board
1313 Sherman St., 7th Floor
Denver, CO 80203

Dear Ms. Mitchell:

The Bureau of Land Management (BLM) Colorado is pleased to provide comments on the first draft of the Colorado Water Plan. The BLM is impressed with the water resources vision set forth by stakeholders across the state, which is to have sustainable and vibrant economies supported by healthy stream systems. The BLM's mission, which is to sustain the health, diversity, and productivity of the public lands for the use and enjoyment of present and future generations, is directly complementary to this vision. The BLM is equally impressed by the magnitude of resources, including monetary, human, and scientific resources that will be necessary achieve the vision of the stakeholders. The BLM Colorado stands ready to partner with the State of Colorado to assist in realizing this vision.

This comment letter does not provide direct comments on specific policies or projects proposed in the Colorado Water Plan. Rather, this comment letter focuses on technical comments that the BLM believes would strengthen the plan, and that would assist the state in accurately describing the role of federal agencies in water supply issues. In addition, this comment letters provides suggestions for additional actions or projects the state may want to consider for inclusion in the plan. Our specific comments are provided in the enclosed document. If you would like to discuss these comments further, you may contact Roy Smith at (303) 239-3940.

Sincerely,

Brian St. George
Deputy State Director
Resources and Fire Management

Enclosure

BLM Colorado Comments on Colorado Water Plan

Chapter 2 – Legal and Institutional Setting

Page 23 – The text that describes the role of federal agencies is accurate with regard to the regulatory functions of federal agencies, but it doesn't fully describe the roles the federal agencies play as managers of large numbers of acres in Colorado. Addressing the federal role as land manager is critical for effective water planning and for approval and permitting of proposed projects. The BLM suggests that section describe how federal agencies provide land use authorizations for water projects that occupy federal lands. The description could include the key federal laws that provide guidance to federal agencies when they issue land use authorizations, including the Federal Land Policy and Management Act, the Endangered Species Act, and the Wild and Scenic Rivers Act.

To give the reader of the plan a better understanding of the federal land use authorization role in water project development, it may be helpful to provide a list of large water supply projects in Colorado that are located wholly or partially on federal lands. From the BLM perspective, good examples would include Clear Creek Reservoir in the Arkansas River watershed and Terrace Reservoir in the Rio Grande watershed, both of which operate on historic authorizations on BLM lands, and Wolford Mountain Reservoir in the Colorado River basin, which operates on a recent BLM land use authorization.

Pages 25 and 26 – The text describing federal reserved water rights exercised by federal agencies lacks a description of federal reserved water rights exercised by the BLM Colorado. The BLM has adjudicated federal reserved water rights for more than 1,200 public water reserves for livestock grazing purposes, for two National Oil Shale Reserves near Rifle, and for the Park Center Well, which provides water for municipal purposes near Canon City.

Chapter 5 – Water Demands

Page 81 – The BLM suggests slightly recasting the discussion of environmental and recreational needs to increase understanding of the plan by the public. The current discussion may lead a lay reader to conclude that "focus areas" identified by the basin roundtables are equivalent to the only stream reaches where there is a concern about maintaining sustainable stream environments, when in fact there are thousands of stream miles that must be maintained in order to provide sustainable watershed functions. The "focus areas" could be described as locations where there are high visibility streams and potential for water use conflicts, but they are only a subset of the streams where sustainable water management is desired.

The BLM acknowledges that it is challenging to express environmental and recreational needs in a quantified manner that would be equivalent to the acre feet needed for future consumptive uses. There are simply too many stream miles to quantify all needs, and environmental needs are generally not consumptive, so it may be misleading to provide a gross acre foot amount.

However, providing only a listing of stream miles with environmental and recreational attributes may not provide the reader with a full understanding of the difficult tradeoffs that will need to be evaluated between diverting water for human usage and leaving water in streams to sustain river-related values. The plan could benefit from pointing the reader to multiple efforts that have been made to quantify environmental and recreational needs in stream reaches with potential conflicts, such as the Arkansas River Flow Needs Assessment that the BLM completed jointly with Colorado Parks and Wildlife. The state could also consider including a goal in the plan to identify stream reaches where conflicts are likely to occur and develop similar quantification of environmental and recreational needs in those focus areas.

In the basin implementation plans, it appears that there is an overwhelming need for easily accessible and understandable science on water requirements for riparian species and aquatic species. The BLM suggests that the state consider the establishment of a geospatial environmental water demands database, similar to what has been established for the State of Arizona by the Water Resources Research Center at the University of Arizona.

Chapter 6 – Water Supply Management

Page 93 – The BLM Colorado suggests that, as part of the development of "low and no regret actions" to address water supply needs, the state may want to consider a commitment to fully assist basins in quantifying environmental and recreation needs. If quantifications of environmental and recreational needs are complete when it is time to implement future water supply projects, the time necessary to implement those projects could be greatly reduced. The quantification information would aid in both project design and project permitting processes.

Page 98 – While developing projects to meet water supply gaps, the BLM notes that all of the basin roundtables have proposed objectives and projects that focus on imperiled and/or endangered species, protecting wetland/riparian areas and protecting recreation. From the BLM perspective, it will be very difficult to meet water supply goals in these arenas without possessing information on flow rates and volumes necessary to support these attributes. However, some of the basin roundtables have not proposed projects designed to quantify non-consumptive needs. The BLM suggests that quantifying recreational and statewide needs be considered as a statewide goal, and that the state could consider work with all basin roundtables to develop quantification projects in locations with potential conflict between consumptive and non-consumptive needs.

Pages 127 through 130 – The plan notes that many basin roundtables identified a significant information gap in relation to understanding environmental and recreational needs. The basin roundtables also noted there aren't sufficient projects in place to address environmental and recreational needs. It appears that the information gaps and lack of projects may be a result of lack of funding and resources at the basin level.

The BLM Colorado suggests that the state may want to consider adding identification of potential funding sources for basin projects on environmental and recreational needs as part of the plan. If legislative action is needed to create new funding sources, then plan could serve as a resource for legislators who are considering funding options. The BLM Colorado notes that the Colorado Basin Implementation Plan has identified funding mechanisms that have worked for projects that have already been completed, and the Colorado Basin Implementation Plan also suggests other potentially viable funding mechanisms.

Chapter 7 - Water Resource Management and Protection

The BLM always seeks to further develop our partnerships with stakeholders and state government in water resource management and protection. Accordingly, the plan may benefit from a specific commitment to working with federal land management agencies on meeting water quality and watershed management objectives. Partnerships on water quality and watershed management could be facilitated if the plan were to fully describe the BLM's role in water resource management and protection, especially since the Colorado Water Plan is both an educational and strategic document. The BLM offers the following observations concerning water resource and management that could be included in the plan:

- Out of the 8.4 million acres in Colorado managed by the BLM, approximately 4.5 million acres are forests and woodlands. This includes 3 million acres of pinon-juniper woodlands, 800,000 acres of deciduous woodlands, and 700,000 acres of coniferous forests.
- The BLM Colorado is involved in multiple forest health initiatives, including the Bark Beetle Collaborative, the Front Range Roundtable, and Cooperative Wildlife Protection Plans.
- The BLM Colorado is preparing a Climate Adaptation Strategy that will identify resources, land uses, and communities that may be vulnerable to climate change and will develop meaningful adaptation strategies. The strategy will be designed to sustain basic ecological processes, including hydrologic function, and to assist communities in developing strategies to adapt to climate change.
- The BLM is responsible for protecting, restoring, and maintaining the chemical, physical, and biological integrity of surface and ground waters that could be influenced by the BLM resource management activities. The Federal Land Policy and Management Act requires the BLM to comply with pollution control laws in land use plans and in land use authorizations. Specifically, BLM complies with applicable federal, state, tribal, and local water quality standards, such as the Federal Water Pollution Control Act and the Safe Drinking Water Act.
- The BLM is very active in source water protection in watersheds that provide municipal water supplies.

- In Colorado, the BLM manages a significant portion of watersheds that provide water to communities such as Parachute, Grand Junction, Palisade, Paonia, Hotchkiss, Norwood, Rangely, Meeker, Rifle, and Canon City. To protect these source water areas, the BLM has entered into a data sharing agreement with Colorado Department of Public Health and Environment (CDPHE), and is currently negotiating a Memorandum of Understanding on source water protection with CDPHE.
- The BLM has an active program to address roads that reduce the functionality of floodplains and wetlands, which in turn have a large impact on water storage and water quality. The BLM frequently takes actions to reroute roads, improve drainage from roads, reduce sediment from roads, and reconnect habitats that are bisected by roads

Chapter 8 – Interbasin Projects and Agreements

The BLM suggests including the Upper Colorado River Wild and Scenic Stakeholder Group as a good example of a functioning interbasin agreement that includes diverse stakeholders (private landowners, conservation groups, local government, and state government) working with federal agencies to achieve water supply management goals.

Chapter 9 – Alignment of State Resources and Policies

Page 288 – The BLM suggests that it may be counterproductive in a long-term plan to broadly state that federal land use plans have upset the balance between state and federal water management authorities, because such language may limit the potential for future cooperation. The disputed issues mentioned in this chapter are limited to some isolated provisions in a few federal land use plans, while the bigger picture is that the overwhelming majority of the language in federal land use plans is clearly supportive of the state's water management goals. The BLM believes it would be more productive to state that the Colorado Department of Natural Resources has MOUs with federal land management agencies concerning water management, and that those MOUs have provided an avenue for productive discussions when these limited conflicts do arise.

Page 314 – The BLM believes that establishment of joint a National Environmental Policy Act review process, beginning before land use authorization applications are submitted for new water projects, would be productive. The BLM's experience is that applicants who are willing to have pre-application discussion of potential impacts and perform analysis of alternatives before submitting land use authorization applications enjoy much shorter authorization times.

Basin Implementation Plans

In general, the BLM believes that the basin implementation plans accurately acknowledge the role that federal land management agencies play in water supply. In addition, the BLM is pleased that the basin implementation plans seek to further develop cooperative relationships with federal land management agencies.

The BLM does not wish to provide comments that are specific to each plan, but the BLM does wish to provide the following overall comments on the basin implementation plans:

- Some of the basins have adopted highly useful tools for assessing environmental and recreational needs, and other basins could consider adopting the same tools. Specifically, the Yampa/White/Green roundtable has utilized "Ecological Limits of Hydrologic Alteration," has conducted an extensive analysis of how instream flow rights compare to actual flow rates found in streams, and has implemented risk assessments for trout, warm water fishes, and cottonwood communities. The Colorado River basin roundtable supports the idea of flow evaluation tools and stream management plans. While some of these techniques require substantial resources to implement, the experience gained in one basin has the potential to greatly reduce the cost of implementing similar analysis in other basins.
- A key component of aquatic ecosystem resiliency is to ensure connectivity between aquatic habitats. With climate change, species will seek to move to cooler aquatic habitats and barriers could inhibit that movement. The basin roundtables could consider projects designed to inventory barriers to aquatic passage, such as road/stream crossing (fords/culverts), headgates, and other water control facilities. Projects that remove or modify these barriers could also be considered.
- A key component of aquatic ecosystem resiliency is aquifer conditions that support continued discharge of groundwater systems to stream systems and springs. The basin roundtables could consider projects designed to inventory groundwater conditions and identify locations where groundwater depletions create risks to streams and springs.
- The basin roundtables could consider expansion of their objectives and projects to support, whenever possible, all native species that are water-dependent, and not just higher profile species. For example, many projects are designed to benefit native trout species, but could also be designed to simultaneously benefit other native species such as long-nosed dace and speckled dace. Similarly, the BLM encourages the roundtables to think very broadly about maintaining health of native species as a strategy to reduce obstacles to future water supply projects. For example, Sage-Grouse are dependent upon discharge from springs. If Sage-Grouse populations are healthy, then impacts to Sage-Grouse are less likely to become an issue in the authorization of water supply projects that occupy sage grouse habitat.

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FEB 23 2015

United States Department of the Interior
FISH AND WILDLIFE SERVICE
Mountain-Prairie Region

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Colorado Water Conservation Board
1313 Sherman Street, Room 721
Denver, Colorado 80203

Dear Colorado Water Conservation Board:

I have reviewed the Draft 2014 Colorado Water Plan and would like to provide the following comments on behalf of the U.S. Fish and Wildlife Service, Region 6, Water Resources Division. First, we applaud Colorado for recognizing that there will be a shortage of water in the future, and for recognizing the importance of water for fish and wildlife habitat. This plan is an excellent first step in trying to meet future water needs for people and for the environment.

A general comment is that the document contains many typographical errors, and should be reviewed both for those and for content. There are a number of sentences that are incomplete or that do not make sense.

On page 23, there is a discussion of the U.S. Fish and Wildlife Service (Service). This discussion only covers the Service's role in implementing the Endangered Species Act. The Service manages eight National Wildlife Refuges in Colorado, and two National Fish Hatcheries. All of these facilities use water, and hold State-based water rights, in conformance with State water law. The plan should include a discussion of these.

On page 25, it states that the Service has "pursued substantial reserved water rights associated with their landholdings in Colorado". I am not aware of any case where the Service pursued reserved water rights. All Service-managed lands in Colorado were acquired by the Service, and would not have reserved rights associated with them.

Page 39 states that the Upper Colorado River Recovery Program provides "limited Endangered Species Act (ESA) coverage for Program participants" on the South Platte. This should be clarified to indicate that this only applies to transbasin diversions from the Colorado River.

On page 42, the existence of a National Wildlife Refuge is included in the discussion of the North Platte Basin. None of the other National Wildlife Refuges or National Fish Hatcheries in

Colorado are mentioned in the document. Water is extremely important for all of these facilities. The plan should mention the other refuges and hatcheries.

On page 48, the link under the Rio Grande Basin Roundtable is to the North Platte Basin Implementation Plan. The link should be changed.

Should Figure 7.3-4 be updated from 2012 to the present?

Thank you for allowing the Service to provide comments. If you have any questions, please contact me at meg_estep@fws.gov.

Sincerely,

Megan A. Estep, Chief
Division of Water Resources, Region 6

Cc: Refuges (ARD)
Ecological Services (ARD)
Fisheries (ARD)

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ITEM 7

These comments are submitted on behalf of the Audubon Society of Greater Denver. We thank you for this opportunity to participate in the formation of the Colorado Water Plan.

We urge that the top priority of the South Platte Basin Implementation Plan (SPBIP) be a creative, intensive water conservation strategy for all the consumptive use sectors of the Basin – municipal, industrial, agricultural. This should take priority even over construction of IPPs, some of which – such as the Chatfield Reallocation project – are of questionable value, offer little in the way of increased water supply, and are highly environmentally destructive, in violation of some of the Goals and Measureable Outcomes described in the SPBIP (see below).   We suggest setting a water conservation standard in the Plan of 10% per person in reduced use – this is highly doable and has been done in other states.

There are studies related to water conservation efforts which should be fully explored and funded, such as those to determine how much water can be stored and withdrawn from underground water storage aquifers, timing for storage and withdrawal, costs, and conceptual designs (see the InterBasin Compact Committee Conceptual Agreement, p. 3). Underground storage will save thousands of acre-feet of water from evaporative loss and make them available for public use.   We will also need rules and regulations for underground water storage aquifers, and the Plan should include recommendations for such.

As we have said before, the Plan needs to include quantification of nonconsumptive needs, including recreational flows, peak flows, minimum late summer, fall and winter flows for streams in the South Platte Basin. West Sage has been assembling such information for certain reaches of certain streams, and this should be broadened to include all reaches of as many streams as possible, including the South Platte itself. In relation to this, the State needs to plan/provide resources for more detailed inventory and assessment of river ecosystem conditions and actual water needs. Only then should IPPs be identified.

We strongly support the Environmental and Recreational Goals and Measurable Objectives included in the SPBIP (P. 1-22 +) especially the following:

NC Measureable Outcome #1: Maintain or increase wetland, lake or stream habitat used by migratory and breeding birds.
NC Measureable Outcome #3: Maintain or increase the number of stream miles…

We want to note for the record that the Chatfield Reallocation project, an Identified Process and Project (IPP) would violate both of these Goals/Outcomes by decreasing wetland habitat and decreasing free-flowing stream miles.

On p. 2-22, South Platte Basin Environmental and Recreational Attributes Table 2-11 watchable wildlife viewing should be included. Currently the table includes only waterfowl viewing. We appreciate and support the inclusion of Audubon important bird areas in this list, but the plan should also specify that such IBAs are a priority for conservation and protection.

Other points:
Trans basin diversions should not be a subject of extensive assessment; the Colorado River is already severely depleted and there is probably not water available for new diversions, especially since climate change is occurring and will result, according to all the major studies, in a diminution of water available in the Colorado River Basin. The South Platte Basin needs to do more with what we have and not waste time considering more trans-basin diversions of questionable value.

The biology of ecosystems must be incorporated along with the engineering and legal structure for stream (water) management.

Land use, growth and water supply MUST be considered together. The SPBIP should make recommendations for incorporation of water supply considerations into land use planning processes and suggest state-wide standards and legislative initiatives.

We look forward to submitting more comments on the complete CWP.

Thank you,
Pauline P. Reetz, Conservation Chairman
Audubon Society of Greater Denver

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ITEM 8

Comments on the Draft Colorado Water Plan

about

Reservoir Evaporation

Respectfully and humbly submitted **by Robert L. Grossman**, PhD (CSU, Atmospheric Science, 1973)

As requested and as a private citizen representing no one but myself, I have the following assessment of an important omission in the current draft of the Colorado Water Plan – EVAPORATION FROM RESERVOIRS, LAKES, AND LARGE CANALS. I will focus my remarks on Reservoirs and Lakes used for domestic, industrial, and agricultural water use. I argue that this crucial and irreversible loss by to the water system has not received the attention it should and that a comprehensive assessment of storage and canal evaporation within the State is wanting. While, as I suggest, we may not know the percentage of water lost to evaporation in our State, better understanding of this critical aspect of water resource management is important for the State to understand its current water supply in the face of rapid climate change and how additional water storage infrastructure will meet its gaps.

For ease in reading and timely submittal, with two exceptions, I'm foregoing the use of references and footnotes. If references are requested, I'll supply them for each statement of fact made.

I will cover these main topics - **History, Monitoring of Evaporation from Reservoirs and Storage Lakes, Climate Change Consequences, and Conservation at the Source** that inspire a **Call for Action**: consideration of a revised Colorado Water Plan, Symposium on Colorado's Reservoir Future, a White Paper for the Governor's Office, and the formation of Scientific Steering Group for Reservoirs and Storage Lakes.

History

Water in the Western USA, which includes Colorado, has been the foundation of recent European settlement and indigenous folk successfully inhabiting the West's desert landscapes for centuries. In general terms, the management of water resources, whether explicitly stated or not, has used the following model for dealing with the scarcity of water resources in the Western landscape:

Input (I) – Output (O) – Evaporation (E) – Infiltration (L) = Storage change (S), *1*

where, Input is encapsulated as a river or stream source but ultimately it is runoff and seepage of groundwater from precipitation, Output is the delivery of a portion of that Input to the community of users, Evaporation is the movement of water molecules from the water surface into the atmosphere, L is infiltration of lake/reservoir water into the ground water system, and S, indicates the change in storage (watercourse, lake or reservoir, even beaver dams!) with time. From a system point-of-view I is a gain while O, E, L are losses as expressed in equation *1* (*1*). In a pristine hydrological system without man-made reservoirs, S is a "residual" in the "balance" equation comprising the terms on the left-hand-side of *1* and is often small. When S is the result of a constructed reservoir or storage lake, S acts as a buffer to the system, changing with time, and ensuring a constant supply of Output and reducing the effect of flooding. In contrast to a pristine system, S in a reservoir system can be large; especially during the seasonal draw-downs and fill-ups of a reservoir.

The argument to be placed before you relies upon *1* so a short discussion of the equation is necessary for clarity. Since all terms in *1* are in units/time, sampling rate and averaging time to estimate and analyze resulting time series of each term in *1* is important and would probably be tailored to the problem at hand. It is important to note that there are time relationships among the terms; for instance, a change in I may affect E after some delay. For most uses, and because of the time relationships among the terms, it would be helpful, perhaps necessary, to have the sampling of all the terms simultaneously made. Consideration of sampling is covered below.

It is my opinion that until recently the emphasis on water management within Colorado has been on the first two terms, I and O, with little regard, if any, to E and L. Evidence of this is within the current Draft of the Colorado Water plan where the string "evap" does not appear!

Historically this is probably due to:

a) the need to insure a constant supply of water, O, to the population by the management of I and O, often the largest terms in the equation over a period of time. Storage, though, varies with time as a result of the time variation of the four terms on the left-hand-side (LHS) of (*1*). There are often large uncertainties in the determination of I, E, L, and S; less so for O, which should be carefully monitored at the dam or water treatment plant. Faced with these large uncertainties, a cogent engineering approach to water management, which appears to have been followed, would be to overwhelm the system with augmented I and conserve O, using S as a buffer against flood, seasonal variability, and drought with small amounts for hydroelectric power (water release = time integration of energy, as in kilowatt-hours) as well as the important task of providing agricultural water during dry, growing seasons. The buffering aspect of S and its large uncertainty caused the water managers of those early times (1880s to 1960s) to neglect E and L, which was often mitigated by choosing reservoir sites with geologically "hard" bottoms, thus considering L negligible terms in *1*.

and

b) the lack of scientific and engineering understanding of the processes of Evaporation and Infiltration in the early days of specifying water storage facilities in a desert landscape. Serious study of the atmospheric boundary layer processes that accompany evaporation was not begun until the 1930's and continues to this day. So water managers had little quantitative information concerning these two *irreversible, or consumptive, losses*, Infiltration and Evaporation. While Infiltration did impact some geological underpinning for the specification of storage areas, Evaporation was elusive. Little was known about it quantitatively and measurement practices were only being tested and formulated at the time.

Colorado State University was, in the early days of reservoir construction, and, currently, is a national and international leader in hydrology and later the emerging field of Boundary Layer Atmospheric Science, which underpins the study of Lake and Reservoir Evaporation. This was especially true after the formation of CSU's Department of Atmospheric Science by Dr. Herbert Riehl in 1961 as well as the historical work in hydrology, watershed management and irrigation at CSU (vis. The Parshall Flume). Professor Riehl was very aware of the West's water problems (in fact, I'm suggesting one of his evaporation loss solutions, high altitude reservoirs, in the Conservation section below) and saw high synergy possible between atmospheric science and water management by locating his "mostly Univ. of Chicago" faculty within the on-going work at CSU. One of my early field experiences as CSU a graduate student in that new department was participation in the Bureau of Reclamation's Lake Hefner

Evaporation Reduction Experiment in Oklahoma City in the summer of 1967. Boundary layer expertise within the State also resides at Univ. of Colorado, NOAA, UCAR/NCAR, research companies, and private consulting firms. Remember that the scientists within these institutions and companies are citizens of the State and probably as interested in its water security future as I am.

As the role of landscape evaporation in atmospheric science gained acceptance, especially with respect to agriculture, the difficulty of adequately estimating evaporation outside of the laboratory became apparent. So in addition to the historical lack of basic understanding of evaporation, water managers at the time were faced with little to no operational methods for estimating it, opening the door to the "educated guess" (often small) or outright "neglect".

Thus there has been little historical incentive to comprehensively address Evaporation with respect to Reservoir and Lake Storage in the West though it appears to be emerging as a recognized problem in Western water management. This oversight needs to be addressed in the current Draft of the Colorado Water Plan.

In fact, <u>the evaporation estimation problem in Colorado remains to this day and should be addressed comprehensively in the Colorado Water Plan.</u> Breakthroughs in scientific approaches to reservoir evaporation estimation can be shared with other Western states less endowed with the expertise Colorado enjoys. Additionally, as I will show, climate change may increase evaporation from Colorado's water storage facilities and storage needs, due to population demand (including the demand for more food and energy), will require the specification of more water storage facilities across the State (and region for that matter). *Evaporation will be needed to be taken into account for any newly specified or augmented storage facility.*

Monitoring Reservoir and Storage Lake Evaporation

I begin this section by posing a series of questions that State and private (licensed) water managers need to answer for the citizenry:

1. What is the current state of estimating evaporation from Colorado Reservoirs and Storage Lakes? What methods are used? When was the last time a comprehensive evaluation of evaporation from Colorado Reservoirs and Lakes made using the latest scientific techniques? Has there ever been a multi-year evaluation to estimate inter-annual variability?
2. Does the State issue regular reports on the management of Colorado's Reservoirs and Lakes, using *1* as a template?
3. How often is evaporation sampled from Colorado Reservoirs and Lakes to estimate the mean annual evaporation for each? Do mean values have estimates of variability associated with them; in other words, what do the frequency distributions look like? Are we missing important episodic occurrences of evaporation due to low sampling rates?
4. If evaporation is an issue with respect to conservation, what can be done to reduce evaporation from current Colorado Reservoirs and Lakes?
5. Major GRACE (satellite retrieval of ground water burden) scientists are resident at the Univ. Colorado. Is this expertise being utilized? GRACE has recently been in the news with respect to the California Drought.

6. Given that snowpack is likely to decrease, air and reservoir temperatures increase, and a drier future atmosphere as projected by climate models, what long-term strategies to reduce reservoir evaporation should Colorado be discussing? Should there be/is a Colorado basin-wide discussion of the reservoir evaporation situation? If there is a basin-wide discussion, how will Colorado prepare for it and who will represent us?
7. As more reservoir storage will be needed as snowpack declines and/or early runoff persists and demand increases, will evaporation be considered in the planning for future reservoirs? If so, how?

As far as I know current State practice for estimating E in *1*, the use of evaporation pans, though inexpensive, may be woefully inadequate. In some cases tabular values from a 33-year old national atlas of evaporation (Farsnsworth, et al, 1982) based on an earlier time period are used. These estimates are then applied to the storage area and partitioned, percentage-wise, across the seasons with no reference for the partitioning values; perhaps from the annual variation of the one station in Colorado, Wagon Wheel Gap, provided in Farnsworth? From the beginning, circa 1920-30's, the use of evaporation pans to estimate evaporation from the large surfaces of reservoirs and lakes has been problematic and a large scientific literature on the topic generally agrees on the method's large uncertainty and inability to adequately estimate E, except, perhaps, in the immediate vicinity of the pan. Here is a quote from a recent (2015) U.S Bureau of Reclamation report (Technical Memorandum No. 86-68210-2014-01): "Evaporation pans are typically used to estimate lake and reservoir evaporation, however the timing and magnitude of pan evaporation is not necessarily representative of actual evaporation from a lake or reservoir for numerous reasons, including significant time lags between peak pan evaporation and peak reservoir evaporation during a year, and has been shown to be highly uncertain (Hounam, 1973; Morton,1979)"; and go on to state they will attempt another estimation method for their study. If a reservoir or lake is large, placement of one evaporation pan, even if correct for its local area, may not be representative of the entire lake surface; in other words the observational "footprint" is not representative of the area being monitored. Other problems are inadequate accounting for precipitation or disturbance by animals and humans as well as inadequate sampling for substantial but episodic evaporation events.

The Farnsworth Atlas is based upon evaporation pan data or free water surface evaporation estimates from meteorological data. It consists of highly interpolated data, contoured across the contiguous USA with no range of uncertainty. The authors give several "warnings" about the use of the map data and the extrapolation data for higher altitudes in the West had large uncertainty. The Atlas is based upon data from about 400 stations across the USA (few in Colorado) for the period 1956-1970 (not even a 30 yr average). Note that NOAA has a 30-year averaging interval to determine climate normals for temperature, humidity, and precipitation for various locations in the United States, revising them recently. The Colorado revised normals generally show state-wide increased temperature and slightly decreased to no change in humidity from the previous period. That combination will increase evaporation as described below in the Climate Consequences section. Furthermore, the scale of the contours in the Atlas indicate substantial high-frequency filtering. The Atlas is not localized enough to account for important topographical effects on reservoir evaporation as described in the Conservation at the Source section. Nor does it give any basis for future planning as inter-annual variability was not discussed nor were any data regarding that important planning variability presented.

If this is the case, this relatively informed citizen can only come to the conclusion that evaporation from Colorado's Reservoirs and Storage Lakes is unknown! This major flaw in the current water management system for the State must be corrected and soon! The current Draft is inadequate and misleading if it is not included. From what I know, we can do better in the 21st Century. Yes, it will be more expensive but far more accurate than the early 20th Century methods currently used. This will be necessary if Conservation at the Source is considered as important as Conservation by the User.

Climate Change Consequences

Whatever the attributed cause, the fact is that global and regional climate is changing; mean temperature is increasing along with its variability. Folks will say that climate is always changing and that it true. However, the rapidity of climate change is catching humanity off-guard and the intensity of this period of climate change is geological in character not to speak of what the future holds. It portents to seriously impact the State of Colorado's economy and population in two major ways: 1) Increasing temperature will affect Coloradans' health, lifestyle, and ability to work (especially those outside) and the State's infrastructure (roads, railways, pipelines); all important to a viable economy and 2) decreasing precipitation, increasing dust-on-snow, decreasing humidity, and increasing temperatures will affect the State's crucial water resources.

In particular E in *1* above will inevitably increase as I will show in a simple parameterization of the evaporative process,

$E = K\ U\ dq/dz,$ *2*

where K is called an Exchange Coefficient (and also can provide for convenient units), U is the mean wind speed, dq/dz is the local vertical gradient of atmospheric moisture. The Exchange Coefficient, K, is determined by observation and has dependence on local terrain, cover, surface layer (first few meters above the surface) stability and the dynamics and structure of the atmospheric boundary layer above the surface layer. Luckily for most Reservoirs and Lakes the difficult problem of evapotranspiration from vegetative cover is not present (but could be a problem at the shoreline), so the E in *2* is from what is specified as "an infinite, plane, water surface" when, in fact, this situation is never achieved as the water surface is not infinite, nor is it "plane" subject to wind waves, white caps, vegetative growth, human intervention, and debris. I must remind the reader at this point that I have noted earlier that this problem of E estimation is important but not easy. Nor is it inexpensive as I'll outline later.

Expanding *2* as in finite-difference form (used in computer simulations),

$E = K\ U\ (q_z - q_{sfc})/(z – z_{sfc})$, where the subscript, z, is altitude above the surface and z_{sfc} = 0, so *2* becomes

$E = K\ U\ (q_z - q_{sfc})/\ z < 1$, indicating water and energy loss from the surface *3*

Now bear with me! As this is fundamental understanding of the role of evaporation in climate-change's impact on water management in the State.

The moisture content of the surface parcel of air in contact with the water surface, q_{sfc}, is known as the saturation moisture content (all the moisture a parcel of air can hold) and is temperature dependent. Importantly, this temperature dependency is non-linear according to the Clausius-Clapeyron equation (can be found in standard meteorology texts). The effect of temperature on saturation moisture content looks somewhat like the well-known "hockey stick" for global mean temperature and population. In other words, saturation water content, q_{sfc}, the amount of moisture that surface air parcel can 'accept' from the evaporating reservoir or lake, increases much more at higher temperatures (summer, climate change) than at colder temperatures (winter, historical, high vs low altitude storage). The moisture content at some distance above the surface, q_z, however, is not saturated because it is out of contact with the reservoir's water surface and more representative of ambient atmospheric conditions, which for the West is DRY. That dry air sucks up water from the reservoir and deposits it as vapor into the atmosphere to be carried by the wind very far downwind; likely out of the State.

So taking the third term in the right-hand-side of *3*, $(q_z - q_{sfc})/ z$, we can heuristically contemplate the effect of climate change on it. The term increases because solar radiation and, as air temperatures increase, sensible heat transfer from the warmer atmosphere into the reservoir's water increase the water surface temperature (only takes a few millimeters for evaporation to take place). In turn the saturation moisture content, q_{sfc}, goes up according to Clausius-Clapeyron because of the temperature increase of the water surface in contact with air parcels. At the same time the atmospheric moisture content, q_z , remains dry or even goes down as the atmosphere becomes drier as projected by climate models. Since z remains constant, the increased difference in the numerator, $(q_z - q_{sfc})$, increases the term, increasing the rate of evaporation. The big question is: by how much?!!

Adding to the problem, current climate projections for the SW USA indicate that surface winds, U in our case, will increase.

So the effect of climate change is to potentially increase reservoir and storage lake evaporation from current, possibly unknown, values and by an unknown amount.

If current practice is inadequate to frame the problem or pose solutions, a plan to investigate the best method of operational evaporation monitoring and implementing the plan will take a concerted effort from experts, management of a complex plan, and extensive field work resulting in a substantial expense. Implementation of a resulting operational monitoring effort state-wide will also be complex and expensive so be prepared. However, water managers, should be able to argue that such expense is cost-effective.

Conservation at the Source

Historically, it appears to this citizen, that water management in the West has been dominated by considerations of Input and Output with a nod to Evaporation and Infiltration. Evidence of this is shown in the location of the reservoirs, which to me were constructed considering only the ease of obtaining Inputs and delivering the Output as well as legal decisions. Current climate change demands this approach be revisited with a highly critical eye. Here is why.

I have outlined in some detail why evaporation potential from reservoirs and storage lakes *will likely increase* as climate changes but climate projections also point to reduced precipitation in the SW USA, reducing Input fundamentally. Furthermore, a combination of warmer temperatures and more dust storms (episodic increases in U) changing the reflective properties of snow will result in early runoff instead of snow storage; this is already happening. Combining increased Evaporation, reduced Input, and, via population increase, demand for increasing Output, and contemplating *1*, makes reservoir and lake storage more important to State water managers than in previous history. By how much and what would be the effect of increasing evaporation? That is the topic of a research effort.

The main conservation efforts have historically centered on the Output component of *1*; for example: xeriscaping, recycling waste water, and other user considerations (shorter showers). There are attempts at increasing Input via the highly uncertain, geoengineering practice of cloud-seeding and the contentious diversions of rivers and streams from “remote areas” to “populated areas”.

In our State’s climate-dominated water future, it is time to consider conservation at the source as much as conservation at the endpoint user and that means serious consideration of reducing reservoir and storage lake evaporation. This is especially true for siting the reservoirs of the future (and there will be many as the population of Colorado and SW USA increases).

Recently some consideration of evaporation reduction has been discussed. The relatively old (1950’s-60’s) use of organic films covering a reservoir as attempted with Lake Hefner, Oklahoma City, OK, in 1967 have been frustrating and now subject to intense environmental impact analysis (EIA) not present back then. Other methods, such as dispersing reflective material and storage underground is relatively untested may not prove feasible and also subject to EIA.

I’m not a water manager, just an old field scientist who has seen better days (and these aren’t bad!), but I wonder what metrics they use to monitor the overall efficiency of their effort. I’d like to propose a metric that might already be in use, using the concept of efficiency as the ratio of Loss to Gain. Contemplating *1*, we can divide it by the Gain in this presentation, Input (I), and not changing the relative importance of each term, to get

$$1 - O/I - E/I - L/I = S/I$$

Rearranging

$$O/I = 1 - E/I - L/I - S/I \qquad *4*$$

The term O/I, Output (a loss) divided by Input (gain), is the overall efficiency of the system and S/I could be construed as a storage efficiency (or potential) and should be related to the head of the reservoir or lake and its time varying surface area; alternatively, (O + S)/I could also be considered overall efficiency. E/I and L/I are also efficiency terms and can be used as metrics for monitoring and policy decisions.

Without any change in storage, a perfectly efficient system, with no evaporative or infiltrative loss, would deliver as much water as it collects; O/I = 1. However, storage change is linked, non-linearly to E and L making the system more complex. Furthermore, the equation needs to be integrated over time, depending upon its use, which further complicates matters. Nevertheless, I propose that the terms, E/I (evaporative efficiency) and L/I (infiltration efficiency), properly handled statistically, can be used as operational metrics.

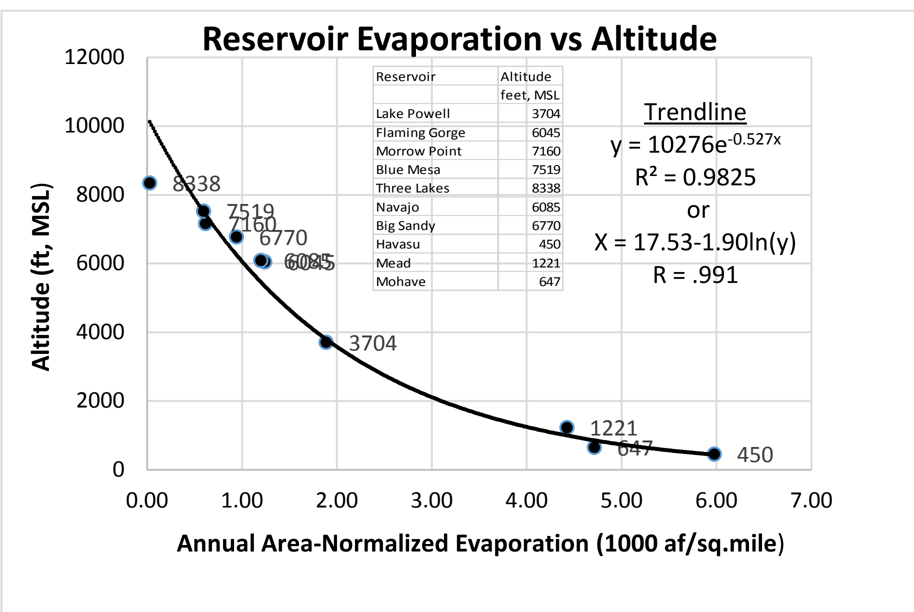
For instance, a proposal to increase the area of an existing reservoir by bringing water from the Western Slope to the Front Range makes no sense if a large portion of that water is irreversibly lost to evaporation. In other words, this NOT “good and beneficial” use according to Water Law and is likely to be challenged in court as part of an Environmental Impact Analysis.

In terms of the metric,

$$\Delta E/\Delta I \ll 1, \text{ for approval of reservoir construction,} \qquad *5*$$

Where Δ is the change of the two components before and after the enlargement. It is up to policymakers to decide how much less than 1 the metric should be in order to approve the enlargement. The same metric could be used for planning new reservoirs and storage lakes. This topic is ripe for a discussion of cost/benefit and risk analysis, which is beyond the scope of this comment, thus my emphasis on statistical integrity of the terms in *1*.

From the discussion of *2*, we saw the dependence of saturation moisture content on temperature and how a slight increase in reservoir surface temperature can greatly increase evaporation potential. Using this principle, the colder a reservoir or lake is the lower its evaporation potential compared to one of similar size but warmer. Since temperature decreases with altitude, higher reservoirs should have relatively lower evaporation as shown in the Figure showing the dependence of annual area-normalized evaporation versus altitude. Note that the list of reservoirs is from a large geographical area.



The non-linear trend line of the highest correlation in the Figure also shows the “power” of the non-linear Clausius-Claperyon relationship with about 50% of the decrease in the first 1550 ft of the 7880 ft range. Blue Mesa and Morrow Point reservoirs at about 7000 ft have only 14% of Lake Mead’s area-normalized evaporation at about 450 ft. It is worth noting that Farnsworth et al (1982) contains two similar graphs (Figs. 5 & 6) for raw pan evaporation observations versus altitude. The recent and area-normalized annual evaporation estimates as shown above considerably improved the correlation coefficient they published (R^2= 0.73).

So placing a reservoir at high altitude with reduced infiltration is the best and most ecologically sensitive way to address the coming problem; as mentioned earlier, this was my late mentor, Professor Riehl's idea, not mine, and data pointing to that solution was available in Farsnworth, et al (1982). Additionally, the reservoir should be relatively small in area but deep to preserve storage volume while reducing evaporation potential.

Beside altitude, two other considerations should be taken into account for current reservoir appraisal and future reservoir siting: Fetch and orientation to the wind. Fetch is the distance air travels prior to and over a given area under consideration; in our case along the mean-wind direction dimension of the reservoir. Orientation is the placement of the reservoir with respect to the mean wind direction, which is time dependent. I suggest seasonal averages of wind-direction, based on the warmest months, should be used to determine fetch and orientation. Fetch and orientation determine the prior conditioning of the air parcel and then the amount of time an air parcel sojourns over the lake picking up water never to be seen again. Evaporation would be reduced for high altitude, cross-wind reservoirs with a relatively moist fetch (forest or grass/shrub land). In contrast, large along-mean-wind oriented reservoirs with fetches over very dry ground are inherently inefficient; a good example is Lake Mead on the Colorado River, a reservoir with extremely high evaporation as shown in the Figure.

Thus for future reservoirs consideration of altitude, fetch and orientation to the warmest months' wind direction should be of equal importance to consideration of ease of obtaining Inputs and delivering Outputs in order to reduce Evaporative loss and increase overall efficiency.

Call for Action: A Symposium on Colorado's Reservoir Future

Colorado is the home of world-class experts and research in water resources covering all aspects of *1*: Input (precipitation, hydrologists, watershed and river management, diversion), Output (water delivery and treatment), Evaporation (Atmospheric scientists, hydrologists), Infiltration (Geologists, hydrologists), and Storage (reservoir management). If not already being pursued, these groups of expertise need to be tightly and officially involved in the consideration of this Draft Water Plan along with stakeholders and policy makers.

I would like to propose that a symposium, covering several days, be convened among the State experts, stakeholders (including the general public), water lawyers, and policymakers (politicians) to take on this important water management problem facing our State: How should the State manage current and planned Reservoirs and Storage Lakes in the Face of Climate Change and Population Growth? With a burgeoning economy drawing in new residents by the million, Colorado needs to do something and soon. The Symposium should also address the impact of increased evaporation potential on the interaction between Upper and Lower Basin States within the context of the Colorado Compact.

The output of the **Symposium on Colorado's Reservoir Future** should be a White Paper to the Governor outlining a plan of action that would augment a revised Colorado Water Plan. It should also form the basis for negotiations between Colorado and the other States within the Colorado Compact. A further and important output of the Symposium would be the formation (with appointments at some future date) of a State Scientific Steering Group for Reservoirs and Storage Lakes that would provide the best and most relevant scientific understanding to the State scientific staff and policymakers for the management and construction of reservoirs and on-going negotiations within the Colorado Compact. The Scientific Steering Group should also be tasked with timely and regular reports on State water reservoir management and construction for stakeholder, Colorado Compact negotiators, and general public interests. The Steering Group will need a staff and supportive budget.

There is little room for error and, given the rapidly changing climate now on record, time may be short.

****End of Comment****

Reference: Farnsworth, Richard K., Edwin S. Thompson, and Eugene L. Peck. 1982. Evaporation Atlas for the Contiguous 48 United States. NOAA Technical Release. NWS 33. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service.