

Large-Scale Management of Fresh Water Resources in the United States: A Federal Policy Recommendation

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Abstract

Recent water shortages in the United States have highlighted the need for innovative large-scale water management solutions. Historically, the federal government has enacted little national-scale policy directed at protecting fresh water supply, although many of the most important water sources in the nation extend beyond multiple state boundaries. In this study, four different policy alternatives are presented and analyzed in terms of their ability to satisfy specific policy objectives related to fresh water management. Through both a comparative analysis of alternatives and suggestions by experts, this investigation concludes that the most suitable federal water management solution should incorporate elements of both water conservation and active reclamation. The policy proposed here stipulates that the USDA ends government subsidies for the growth of water-intensive agriculture in drought disaster areas, and that 80% of the revenue generated by nullification of these subsidies will be used for investment in desalinization, while the other 20% is used to extend the 48C clean manufacturing tax credit in water-abundant regions. This policy would require no direct financing from the federal government and would mitigate water shortages by simultaneously disincentivizing inefficient water use and actively securing new sources of fresh water.

Introduction

Fresh water ranks as one of the nation's most important natural resources, as it is critical for public health, manufacturing, agriculture, and national energy independence. The importance of clean fresh water makes it a rich topic for rigorous environmental policy assessment.

Population growth and widespread drought have contributed to an impending worldwide shortage of fresh water. By the year 2030, world demand for fresh water will exceed supply by roughly 40% [1]. In the U.S., even during non-drought conditions, at least 36 of the 50 states experience local, regional, or statewide water shortages each year [2]. A significant portion of accessible fresh water is becoming unusable because of increases in pollution. Stormwater and urban runoff are responsible for introducing contaminants like sodium, sulfates, and magnesium into fresh water supplies, and 29% of the salinity of fresh water sources in the U.S. can now be attributed to man-made materials like those used as salts for melting snow and ice from roads [3]. An inadequate clean fresh water supply can significantly impede agricultural output, water-intensive manufacturing, and hydroelectric power generation [4]. Energy production in the U.S. is closely related to the availability of fresh water. Hydraulic fracturing for the extraction of natural gas and petroleum requires millions of gallons of water per day, and this water is never recovered [5]. As aquifers are depleted, fresh water shortages will become more severe, and options for incentivizing water recycling, desalinization, and conservation will undoubtedly face lawmakers for decades to come. New legislation will serve as a crucial tool in the effort to protect our fresh water.

Currently there is very little federal policy directed at protecting and managing the supply of fresh water in the United States. Most water legislation is implemented at state and local levels because of disparities in water abundance across different regions of the country. However, consistent water policy at the federal level would allow for more effective management of water resources which span across state lines and help to ensure U.S. economic security. As the demand for water increases, it becomes more important to develop national policy which aims to protect the nation's fresh water supply.

Most water management in the U.S. is performed by a variety of competing private and public entities at the local and state levels. Federal power to manage water resources is currently divided between nine different agencies, and within just the Department of the Interior, eight different subdivisions have influence over water policy [6]. This organization scheme allows for regulations that can accommodate differences in regional water abundance, but it fails to address issues which span across state lines. Rather than a patchwork of state regulations, consistent federal guidelines are needed for managing the water resources of large regions. Federal legislation and oversight can allow for the creation of consistent standards for water quality, the collection of national and global data for disaster planning, and for moderation of legal disputes between states [7]. The patchwork of state laws which govern water property rights and pricing schemes make water allocation increasingly inflexible.

Failure to efficiently allocate water in the future will become more costly if economic growth becomes limited by water shortages [8]. This makes it increasingly important for federal legislation to provide tools for ensuring that appropriate allocation of water takes place in the near future.

Renewable watersheds like the Colorado, Sacramento-San Joaquin, and Klamath have been severely over-harvested, and non-renewable aquifers under the Great Plains and California's San Joaquin Valley will be depleted in the coming decades. Mitigation of large-scale water shortages like these can be achieved at the federal level only by a centralized, concerted effort. As the demand for water increases and fresh water reserves are depleted, it becomes critical that federal policy aims to efficiently secure and maintain the nation's fresh water supply.

Scientific Background

There is an enormously diverse network of sciences which relate to the large-scale management of fresh water resources. While physical sciences like hydrology and climatology are inexorably linked to water supply, socioeconomic factors play a significant role as well. Although the causes and effects of water shortages have been studied extensively, many scientific questions remain about the best practices for water management. In order to effectively manage the nation's fresh water supply, it is important that policymakers understand issues stemming from both the physical and social sciences related to water extraction, usage, and sustainability.

By modeling climate change and its connection to the hydrologic cycle, scientists have learned much about how water is transported to lakes, rivers, and aquifers, and how the quantity and quality of this water might change in the future. By studying historic rainfall records, scientists have determined that over 30% of the U.S. is experiencing a moderate drought, and that because of this, 7 of the 50 states are witnessing significant declines in agricultural output, experiencing frequent water shortages, and implementing mandatory water use restrictions [9]. Climatologists contend that global temperature increases will likely exacerbate these already extreme drought conditions in the next few decades [10]. Hydrologists have determined that groundwater levels in almost every aquifer in the U.S. have decreased during the past 60 years [11] and have concluded that much of this depletion is due to recent increases in groundwater extraction, from an average of 9 km³ of water per year from 1900 to 2008, to almost 25 km³ of water in 2013 [12]. Because water is being

removed from aquifers more quickly than it is being naturally replenished, most analysts agree that current management practices and water extraction rates are unsustainable [11]. However, scientists are now using advanced hydrologic models to assess the feasibility of aquifer recharge and recovery, a practice in which aquifers are intentionally filled with fresh water for storage and later extraction. Aquifer recharging may drastically reduce the amount of water lost to evaporation from reservoirs, and may significantly improve water quality [13]. Overall, findings in the physical sciences indicate that the depletion of aquifers and the increasing volatility of weather due to climate change have made the nation more vulnerable to catastrophic drought and water shortages. The scientific results make it clear that swift, effective measures must be taken to avert severe water shortages in the U.S. in the near future.

A diverse set of socioeconomic factors can influence water usage and management as well. Shortages of water become more severe and economically crippling when they occur across larger populations, which means that the migration of people around the country strongly affects water availability and usage. The southwestern U.S., the fastest growing region in the nation, has been hit especially hard by recent drought [14]. The region contains 36 million people and 15% of the nation's agriculture, all of which depend almost entirely on water from the Colorado River [15]. Because of rapid population growth in the Southwest, the major reservoirs along the Colorado River, Lake Mead and Lake Powell, are being drained at unprecedented rates. Some analysts assert that low water levels in Lake Mead are already causing declines in electricity production from Hoover Dam, and that a complete disappearance of the lake is possible by 2050 [15]. It is clear that migration trends around the country should influence water management practices.

Energy markets can affect water abundance as well. Recently it has become economical to extract natural gas and oil from U.S. shale deposits by hydraulic fracturing (fracking), which requires thousands of cubic meters of water for fracturing fluid at each well, most of which is never recovered [16]. This means that future trends in energy production by fracking and hydroelectricity are undeniably linked to water extraction and usage. The types of sectors which dominate the U.S. industrial landscape clearly have a large impact on water usage as well, as over 90% of the water used for industrial processes in the U.S. is fresh water [17]. This means that proper water management must accommodate the requirements and flexibilities of different industries in regards to their water usage.

Although most analysts agree that by 2030 the demand for fresh water will exceed supply by around 40%, many scientific issues related to water management in the U.S. remain

uncertain [4]. Researchers use increasingly complex models to estimate the status of future water reserves and socioeconomic climates, but it is difficult to predict the details of long-term drivers and consequences of severe water shortages. While the scientific community agrees that global warming may lead to more severe droughts, climate models cannot accurately predict the location, frequency, or duration of such droughts [18]. Even the rate at which groundwater can be sustainably extracted remains under dispute. Traditionally, the safe-yield concept placed a limit on the amount of water that could be safely harvested from an aquifer. However, recent studies suggest that the safe-yield idea may be unsustainable for long-term water extraction because it does not consider auxiliary environmental impacts and interactions between different aquifers [19]. Furthermore, it is difficult to predict where significant population shifts within the country will occur in the future. Researchers have incomplete knowledge about the dynamics of migration models, including the causes and consequences of migration over extended time periods [20]. There is a large body of unanswered scientific questions, both physical and socioeconomic, which relate to nationwide water management. These scientific uncertainties make it very difficult to implement and sustain effective large-scale water management practices.

Although much of the science related to large-scale fresh water management has been studied and modeled extensively, many scientific questions remain about the future state of the environment, climate, and socioeconomic atmosphere of the U.S. These factors can all have profound effects on water abundance, usage, and management practices. For effective policy decisions to be made at the national level, it is important that the conclusions and limitations of science are understood clearly by lawmakers.

Relationship to Existing Laws

Federal water policy in the U.S. has traditionally been focused on improving water quality and monitoring pollution. However, federal legislation has also played an important role in fostering compromise between different states and in managing disputes about the rights to water sources which span across state boundaries. Because of the large diversity in state-level water policies, policymaking at the federal-level remains more of a reactive rather than progressive process in the U.S.

Traditionally, water policy related to supply management at the federal level has been primarily concerned with data reporting and leadership. The USDA and EPA report levels of efficiency in water usage trends across the country so that states can review the areas in which

they can improve [21]. The EPA also manages a program called WaterSense, which attempts to educate water consumers about their usage efficiency. In 2003, the Department of the Interior established a program called 2025 which was meant to address water shortage issues. The program offers grant opportunities for projects directed at improving efficiency in water usage and provides federal consultation to states, municipalities, and tribal lands with regards to water abundance and conflicts [22]. Although the Pollution Control Act Amendments (including the CWA) established in 1972 provided guidelines for the quality of the nation's water, little progress has been made towards creating cohesive federal policy directed toward the management or scarcity of water resources [23]. While states are responsible for adhering to the CWA by establishing technology standards and flow discharge limits for water sources, the EPA has authority to take over these duties if states fail to meet guidelines set by the law. The lack of consistent federal policy focused on water scarcity is primarily due to an absence of centralized authority over water resource management. The responsibility for implementing and assessing water policy is currently fragmented across 13 congressional committees, 23 subcommittees, 8 cabinet-level departments, 6 independent agencies, and 2 white house offices [24]. To further exacerbate this fragmentation, the organizations with authority over water policy are not the same as those with the power to fund projects related to water infrastructure or management.

The primary role of the federal government in managing the supply of large-scale water resources has been to act as a mediator between different states when a conflict about water rights arises. The Colorado River Compact (CRC), established in 1922 between 7 different states and the federal government, allocates water rights between upper Colorado basin states and those of the lower Colorado and allows for the development of federal water infrastructure in the Southwest by the U.S. Bureau of Reclamation [25]. A list of new CRC guidelines set to last until 2026 was signed into federal law by the Secretary of the Interior in 2007. These interim mandates address issues related to water allocation during times of significant shortages [26]. More recently, a 1985 agreement called the Great Lakes Compact (GLC) was formulated. This compact outlines guidelines for the collective management of the water in the Great Lakes by 8 different states and the Canadian provinces of Ontario and Quebec. The GLC was signed into federal law in 2008 and requires parties to submit proposals for diverting or using large amounts of water in the basin [27]. Today, there are over 26 different interstate water allocation compacts like the CRC and the GLC [28]. Because of the differences in water allocation policies across states, it has been quipped that the country uses fifty different policies related to water management [29]. Although the

large variety of interstate water compacts allows for allocation flexibility between different regions of the country, compact rules are by nature complex and may sometimes conflict with compact agreements in adjacent states.

The federal government also contributes to large-scale water resource management by issuing water rights rulings in the U.S. supreme court. In 1908, the supreme court ruled in the *Winters vs. United States* decision that the federal government was entitled to water rights whenever federal land is put aside for public domain. This court decision awards the federal government with enough water to fully satisfy its needs for the development of Indian reservations, National Parks, and National Forests [30]. Since the early twentieth century, the *Winters vs. U.S.* decision has set the precedent for water disputes between the federal government and states. The supreme court has also been active in conflict resolution between states. In 2013, the supreme court ruled in *Tarrant vs. Herrmann* that Oklahoma was not obligated to sell any water rights to Texas, which cemented the authority of the Red River Compact, signed between the two states and ratified by congress in 1980. This court decision sets an important precedent for protectionist movements by states, in which states may reserve their rights as dictated by interstate compacts even during times of significant water shortages in adjacent states [31].

Although water policy at the federal level has traditionally been directed at mitigating pollution levels, the federal government plays an important role in water management practices by fostering compromises between states and by setting water rights precedents in the U.S. supreme court. However, little cohesive federal-level policy is aimed at directly mitigating the causes and effects of large-scale water shortages.

Policy Objectives

In order to carry out an effective analysis of a potential federal policy, a set of criteria must be developed with which to evaluate the quality of the policy. An assessment of how well the proposed policy meets each criterion provides a measure of how well the policy will meet its objectives if it is passed into law. For the implementation of a federal-level fresh water management policy, six criteria will be evaluated in detail.

- **Effectiveness** is one of the most fundamental objectives of any policy. The passage of an ineffective policy can result in a significant waste of resources and exacerbate time-sensitive problems. For a large-scale water management policy to be effective, it must help significantly mitigate water scarcity and provide guidance for how water

consumers can responsibly manage their water supply. It should help to improve both the quality and the quantity of fresh water reserves in the country. Because water resources are being drained at unprecedented rates, an effective policy should produce positive results relatively quickly, before aquifer depletion or climate change can cause catastrophic water shortages. Finally, the policy should be framed in a consistent and cohesive way which helps to consolidate the large and diverse patchwork of current state and local-level water policies currently in use in the U.S.

- **Cost** is one of the primary reasons that pieces of effective legislation are often delayed or blocked. A successful water management strategy should, after a period of time, allow water usage and storage to become more cost-effective than it is now. A policy which incurs initial costs, for the development of infrastructure, for example, should eventually help lower the cost of water, because delaying the implementation of such strategies until water is less abundant will inevitably become more costly overall. It is important that a federal water policy makes progress towards lowering or maintaining the long-term cost of water usage. Such a policy would be cost-effective even if initial costs are incurred. Strict regulations or taxation on industrial water usage can be costly as well, and may limit economic output in certain sectors. These costs, even though not directly incurred by the federal policy, should be considered during evaluation of policy alternatives.
- **Political Feasibility** is critical for any policy. Even an extremely effective federal-level water policy cannot be implemented unless it is practical and realistic. A successful water policy should not require significant restructuring of government agencies, creation of large new federal bureaucracies, or development of expensive enforcement agencies. It should be possible to implement, monitor, assess, and enforce without encountering significant environmental costs or socioeconomic obstacles. In order for a federal-level policy to be politically feasible, it must also appeal to people of different political backgrounds. Legislation which seems to favor one group of people over another will face more resistance from both lawmakers and the public.
- **Technical Feasibility** refers to how physically plausible the policy is. This objective is especially important if the proposed policy requires new infrastructure, technology, or improvements in the efficiencies of industrial processes. An effective federal-level water policy may require the development of new infrastructure like pipelines, dams, desalinizations plants, or aquifer pumping stations. For this development to take place,

cost, land usage, and resource allocation should be kept to a minimum in order to retain technical feasibility of the plan. Using well-studied, established techniques and tools will help to ensure that projects are technologically feasible.

- **Sustainability** of a large-scale water management policy is crucial for the policy to be deemed effective. One of the main objectives for federal water management is to ensure that trends in water usage can be sustained over extended periods of time. Sustainability becomes especially important as the country experiences the effects of climate change. The proposed policy should aim to mitigate water shortages not only in the present socioeconomic and climatic settings, but also in the future when drought may become worse for larger populations living in arid regions. A policy which is sustainable should exhibit a degree of flexibility so that management practices can effectively adapt to changing climatic or socioeconomic conditions as time goes on. A sustainable water management policy will also exhibit durability and resilience in response to acute weather events. For a policy to be successful, it must not only be effective during typical climatic periods, but must also mitigate shortages or abundances of water during abnormal weather patterns.
- **Equity** for all parties affected by the legislation is important. The point of enacting a federal-level policy is to ensure equity in water allocation and usage rights throughout the country so that regional differences in water abundance don't create significant social or economic disparities. Large-scale water management practices which strongly favor certain industries, regions, or social groups over others are not equitable. A policy which is inherently inequitable is also generally less effective.
- **Environmental Impact** is an important criteria to consider during the analysis of any policy alternative. Alternatives which cause significant negative environmental impacts are politically unfeasible because of their likely opposition from citizens, human health groups, and environmental groups. Since the presence of clean, fresh water is an integral part of every healthy environmental ecosystem, water policy should incorporate management practices which pertain not only to water for human consumption, but to natural environmental processes as well.

Policy alternatives will be evaluated in relation to how well they meet the six criteria described above. A successful water management policy at the federal level will have aspects of all the above objectives while minimizing undesirable characteristics.

Political Stakeholders

For evaluating the political feasibility of each policy alternative, it is important to identify the major stakeholders associated with the proposed legislation. Different stakeholders can hold vastly different perspectives regarding policy choices, so an alternative which is politically feasible generally must be desirable to the majority of the stakeholders involved. The stakeholders discussed in this analysis are:

- Water consumers - any parties who purchase water for residential, commercial, or industrial use
- Residents - any parties who live or own property in close proximity to land which is directly affected by the proposed policies
- Environmentalists - any parties whose primary concern is the protection of the environment, including private citizens, nonprofit groups, and government agencies such as the EPA
- Water utility companies - any entity who makes money by selling water to other parties
- Land developers, entrepreneurs, & technologists - any parties which benefit from the building or implementation of facilities, infrastructure, or new technologies
- Public health advocates - any party which is primarily concerned with human health, such as private citizens, healthcare providers, and government agencies like HHS
- Politicians & states - this includes all public servants in governance positions, including city council members, mayors, governors, members of congress, agency directors, and state governments

The feasibility of each alternative can be analyzed most concisely and effectively by relating it to each of the stakeholders involved. Although some of the stakeholders may have a significantly stronger influence on policy decisions than others, it is instructive to predict each of their perspectives on the proposed alternatives.

Policy Alternatives: an Economic and Political Analysis

For mitigating the scarcity of fresh water resources in the U.S., several federal policy alternatives are described below. An economic and political analysis of each alternative is presented

as well.

Reduce subsidies for water-intensive agriculture in water-scarce regions

This policy alternative mandates that when the USDA designates a county as a primary or contiguous drought disaster country, farmers will receive no USDA subsidies for growing beef, cotton, sheep, pork, chicken, almonds, walnuts, rice, soy, wheat, alfalfa, or corn in that county during the following year.

The USDA spends \$14 billion each year insuring farmers against the loss of income from crops, which includes nearly all of the corn, soybeans, cotton, and wheat grown in the country [32]. The USDA also spent over \$4 billion between 1995 and 2012 to fund at least 12 different livestock subsidy programs, including the livestock compensation program, emergency livestock feed assistance, and livestock forage disaster program [33]. Although these subsidies help stabilize food prices and reduce risk to farmers, they also support production of the most water-intensive crops in the country, which include corn, soy, alfalfa, and the most water-intensive meat to produce, beef. In addition, the land used to produce these crops is some of the most heavily irrigated land in the U.S., and lies in some of the most commonly drought-stricken states, including California, Texas, Florida, and Nebraska.

Although the land dedicated to growing sorghum, an extremely water-efficient crop, has gone up 40% in the last two years, little change has occurred in the total production of corn or soy, the nation's most ubiquitous crops, mainly because of the strong subsidies which reward corn and soy growers [34]. Furthermore, each year the U.S. consumes 65 trillion gallons of water for the production of heavily-subsidized beef, the largest source of livestock water consumption [35]. Government support of large-scale, water-intensive agriculture in arid regions is irresponsible and financially inefficient.

The USDA currently publishes yearly data which assigns each county in the nation a secretarial drought designation. This means that implementing this policy alternative would not require extra funding to designate drought regions. Matching a farmer's address with the drought designation in his or her county can be done electronically, and should not require annual labor once it is implemented. If it takes ten federal employees to implement an electronic system which matches the type of crops a farmer produces with the county the crops were grown in and compares this to the list of drought disaster counties designated by the USDA, we can estimate the labor costs involved. It is estimated that the average federal government employee receives a salary \$78,500 [36]. Employee benefits make up roughly 35%

of the cost of a federal government employee [37], so we can estimate that an average federal employee costs about \$120,000 per year. Assuming that implementation of this matching system could be accomplished in one year, it would cost roughly \$1.2 million to pay these employees.

Other costs of this policy are related to farmers and the goods that they produce. The policy will directly cost farmers several billion dollars worth of subsidies for growing food and raising livestock each year [32, 33]. This may result in a loss of agricultural jobs, a decline in purchases of equipment and feedstock used for agricultural purposes, and a loss in government revenue generated from taxes on these jobs and purchases. Government costs associated with unemployment and supplemental nutrition programs may also increase. A removal of these subsidies and insurance programs will undoubtedly make growers more prone to risk, which can lead to higher volatility in food prices and shortages of some types of crops. This will likely lead to an increase in the price of certain foods, which translates into price increases for all of the products made from these foods. The economic ramifications of this policy alternative have the potential to affect not only farmers, but all consumers, distributors, and exporters of food grown in the U.S.

Agricultural producers currently provide information, like crop types and their quantity, to the USDA about the food and livestock they produce so that they can receive growing subsidies and crop insurance. This means that little additional monitoring of crop output from different farms will be needed for the implementation of this policy alternative.

Overall, the most significant costs associated with this policy alternative will be suffered by agricultural industries, food industries, and consumers. Federal and local governments may also experience costs stemming from reductions in tax revenue and increases in unemployment.

Political Stakeholder Analysis

- Water consumers who grow agriculture in drought-prone areas will strongly oppose this measure, as it reduces the subsidies they receive from the USDA. Consumers who use significant amounts of water for industries other than agriculture may support this alternative, because it may result in a reduction in the demand for water, which could lower the price of water in that region. Consumers in water-abundant regions may support the policy, as it incurs no cost to them and indirectly makes their land more valuable.
- Residents who do not cultivate agriculture in arid regions will support this measure

because it encourages water conservation and may lead to lower water prices in the surrounding areas if demand drops. Conversely, residents who raise livestock or water-intensive crops will oppose this policy because it reduces their federal subsidies.

- Environmentalists will likely support this alternative because it encourages conservation and discourages agricultural practices which drain the landscape of precious water resources like rivers and aquifers. It also gives farmers incentives to grow water-efficient crops, which are more likely to be native to arid regions. Growing native plants can be beneficial to the entire ecosystem, as it provides habitat and nutrition for native animals and may improve soil quality.
- Water utility companies will support this measure because it will decrease the demand for water in arid regions. Reduced water demand during times of shortage leads to lower operating costs for utilities, which can result in higher profit margins.
- Land developers, entrepreneurs, & technologists do not have a large stake in this alternative, but they may have mixed opinions about it. Land developers are less likely to develop arid land for water-intensive agriculture, but may see the opportunity to grow water-efficient crops on lands that have been abandoned by farmers of water-intensive crops. The price of land which has traditionally been used for growing water-intensive crops may fall in arid regions, which encourages the purchase and development of the land for other uses.
- Public health advocates do not have a large stake in this alternative, but they may support it because it could ultimately lead to lower water demand in arid regions, which lowers water costs and allows residents to purchase more water for household and sanitation purposes.
- Politicians & states in arid regions whose constituency relies heavily on agriculture will strongly oppose this plan, along with states which receive significant amounts of agricultural subsidies from the USDA. The highest opposition will come from arid regions which cultivate large amounts of water-intensive agriculture. States which are not at risk for drought will support the alternative, as it encourages farmers to move from arid regions to more water-abundant states.

Extension of the 48C manufacturing tax credit in water-abundant regions

This policy expands the 48C advanced energy manufacturing tax credit by \$500 million to be used by 2025, and requires that the manufacturing be located in a water-abundant region as designated by the Bureau of Reclamation. The U.S. Bureau of Reclamation will be responsible for identifying arid counties which currently suffer from, or have the potential to suffer from long-term water shortages.

It is important to attempt to limit large-scale water-intensive urban and industrial development in water-scarce regions. It is expected that the urban population in the world will double during the next 30 years, and that most of this urbanization will occur in arid regions that are at risk for frequent water shortages [38]. This trend is already prevalent in the U.S., as the arid Southwest is the fastest growing region in the nation. Incentives for development in water-abundant regions would discourage growth of areas in which water shortages are common.

The cost of this alternative is dominated by the \$500 million loss in tax revenue to the federal government. It will also require an assessment by federal employees as to whether applicants for the tax credit meet the criteria to qualify. If a team of 10 employees at the Bureau of Reclamation is responsible for assessing regions for overall water abundance and coordinating with the IRS for issuing the tax credits to qualifying facilities, then at an average cost of \$120,000 per year for 10 years, ten employees would cost the government roughly \$12 million.

This policy alternative will impose an indirect cost on arid regions, as it incentivizes the development of manufacturing facilities in water-abundant regions and discourages the transport of new industry and jobs to dry areas. This reduces household incomes and limits revenue generated by local governments in dry regions.

One of the primary costs associated with manufacturing is that it can generate large amounts of industrial waste and consume significant amounts of energy. Even plants which manufacture environmentally-friendly products, like silicon-based photovoltaics for example, still generate toxic byproducts and solvents which must be disposed of. The establishment of new manufacturing plants will impose environmental costs on the communities and ecological systems adjacent to the plants. Building factories can lower property values in the surrounding areas and may result in increases in electricity prices if the energy consumption of new plants is high.

Overall, the primary costs of this alternative will be paid for by the federal government in

the form of tax revenue losses. Costs will also affect households and local governments in arid regions in the form of low growth in the manufacturing sector, and will affect communities in the proximity of new factories in the form of environmental damages and property value depreciation.

Political Stakeholder Analysis

- Water consumers in arid regions will support this alternative, because it will lead to decreased water demand and lower water prices. In water-abundant areas, consumers may be hesitant to encourage water-intensive manufacturing, because it may ultimately lead to higher water prices.
- Residents of arid regions will oppose this plan because it discourages investment in their communities which can lead to new job creation. In water-abundant regions, residents may have mixed perspectives. Incentives for new manufacturing plants encourage job creation and the development of infrastructure. However, many residents may not want industrial plants being built near their homes, as this can lower property values and put them and their communities at risk for exposure to hazardous industrial waste.
- Environmentalists in arid regions will support this plan because it discourages the removal of water from rivers and aquifers. In water-abundant regions, environmentalists may oppose the plan because the development of manufacturing facilities leads to increases in industrial waste and pollution near those facilities.
- Water utility companies in arid regions will strongly support this measure. It will lower the demand for water where water is scarce, which lowers costs to water utilities and prevents them from having to implement new infrastructure or regulations for accommodating the addition of new high-consumption water users.
- Land developers, entrepreneurs, & technologists in water abundant regions will strongly support this plan because of the investment opportunities for new manufacturing plants. For the same reason, they will oppose it in arid regions, because it discourages these new opportunities.
- Public health advocates do not have a large stake in this alternative, but they may support it because it lowers demand for water in dry regions, which allows households to consume more water for residential and sanitation purposes.

- Politicians & states in arid regions will strongly oppose this plan. It discourages new development and job creation. In water-abundant regions however, politicians and states will support it, as it encourages investment, development, and job growth.

Investment in desalinization

This policy stipulates that the federal government provides a desalinization funding package of \$5 billion, consisting of \$1 billion awarded to scientists in the form of NSF grants for desalinization research, and \$4 billion to subsidize the costs of new desalinization projects.

Desalinization is an important technology for several reasons. Agricultural waste and urban runoff contain such high concentrations of salt that 29% of the salinity of fresh water sources in the U.S. can now be attributed to pollution [3]. Many groundwater sources which were used in the past for drinking water and irrigation are now too salty to use without prior desalinization treatment. In addition, some of the most arid states with the largest population growth, California, Texas, and Florida, are also some most drought-ridden, yet these states all have large coastlines which are ideal for desalinization development. The establishment and use of desalinization processes in these states would help alleviate water shortages for decades to come.

The main factor which currently limits large-scale desalinization is cost. But new technologies, such as flow-through electrode capacitive desalinization, promise to be more energy-efficient, cost-effective, and faster than traditional desalinization methods [39]. Innovative methods for the desalinization of ground water, such as those powered by solar receiving systems, are also being pursued [40].

The financial cost of this alternative is dominated by the \$5 billion package itself. However, smaller financial costs will be incurred as well. The Department of the Interior must pay employees to review potential desalinization projects and determine whether they should be awarded funding. If this requires a team of five reviewers which cost an average of \$120,000 per year during a three year review period, the employees would cost about \$1.8 million. By the same reasoning, if the NSF must pay employees to review grant applications for the \$1 billion in research funding, this may require three employees. If this money is distributed over the course of three years, it would cost roughly \$1.1 million to employ the grant reviewers. It is expected that the total cost associated with hiring federal employees to carry out the policy over 3 years will be around \$3 million.

Although more difficult to quantify, the development of desalinization projects also comes with large environmental costs. Fish, plankton, marine plants, and other sea life can get

killed inside seawater intake lines at desalinization plants. After about 1 gallon of freshwater is extracted from every 2 gallons of seawater, the remaining brine solution is deposited back into the ocean. Although not studied extensively, it is expected that the high-concentration of salt in this waste stream is harmful plants and animals in the vicinity of the plant, and may cause significant reductions in sea life. This could cost the local seafood industry valuable revenue, as less fish and marine food sources will be available for harvest.

The large consumption of electricity represents another significant cost associated with the operation of new desalinization plants. Most reverse-osmosis plants generally consume around 15 MWh to produce 1 million gallons of fresh water [41]. This enormous energy demand places strain on the electric grid and can lead to increased power shortages, higher volatility in energy rates, and higher electricity costs to consumers in the surrounding areas.

Finally, tourism associated with the beach can represent one of the primary sources of income for coastal communities. Subsidies for construction of desalinization plants will encourage new plants to be built, which can impose a visual blight on the surrounding coastline, reduce tourism, and ultimately harm the economies of coastal areas near desalinization plants. In addition, the construction of a large, industrial plant in an otherwise quiet coastal community may significantly lower property values, which could ultimately lead to a reduction in property taxes collected by local governments.

Political Stakeholder Analysis

- Water consumers will have mixed opinions about this alternative. Although it guarantees water security in the future, the high cost of producing fresh water by desalinization may ultimately be translated to consumers in the form of higher water prices.
- Residents of areas near desalinization plants will likely oppose this alternative. While the availability of water may increase, it is possible that property values near the desalinization plant will drop. High salinity levels in seawater near the plant may also pose a risk to recreational activities, such as fishing and whale watching. Because of environmental degradation, tourism in the area may also decrease, which can hurt the local economy. Finally, the high demand for power at desalinization plants may increase volatility of electricity prices for residents nearby, which can lead them to oppose the construction of new plants.
- Environmentalists have mixed feelings about desalinization. It represents a clean, sustainable way to generate fresh water without the need for diverting rivers or depleting

important aquifers. However, desalinization can strongly damage aquatic ecosystems around the facility, including marine plants and animals, beaches, and sensitive wetlands.

- Water utility companies would benefit from subsidized desalinization plants. While these plants are generally too expensive to be commercially viable at present, assistance from the federal government would allow utility companies to build plants for use when water scarcity reaches a point at which desalinization becomes financially advantageous.
- Land developers, entrepreneurs, & technologists would strongly support federal subsidies for desalinization implementation and research. Funding for new plants presents opportunities for developers and entrepreneurs, and federal grant money can instill life into research projects for technologists and scientists.
- Public health advocates would likely support desalinization projects. The construction of plants would secure regional water resources for decades to come. The availability of fresh water contributes to human health, especially in times of drought and extreme heat events.
- Politicians from coastal regions and & states with coastlines would strongly support new desalinization projects. Landlocked states would likely oppose the measure, as it benefits coastal states far more than landlocked ones. Politicians opposing the alternative can cite the high cost of desalinization and the potential environmental risks as reasons for their opposition.

Investment in cloud seeding

This policy provides a package of \$1 billion from the federal government, \$800 million of which will be given to scientists in the form of NSF grants for cloud seeding research, and \$200 million of which will be used to subsidize the costs of building new cloud seeding infrastructure for utilities and agricultural agencies.

Similar in structure to the previous policy alternative, investment in desalinization, this alternative provides federal funding for both scientific research and the development of infrastructure needed for large-scale cloud seeding. Although it has not been widely considered for drought mitigation, increasingly severe water shortages and the use of drones for airborne cloud seeding can make weather modification a significantly more cost-effective alternative

in the future. Indeed, it has been predicted that cloud seeding can increase precipitation levels by up to 15%. In California alone, water agencies and utilities spend up to \$5 million annually on cloud seeding, which is estimated to boost current water runoff levels by at least 4% [42, 43].

In an effort to better understand and utilize cloud seeding, the federal government has spent over \$300 million on R&D for weather modification since the 1960's [44]. However, the lack of a coordinated national research program has delayed scientific and technical advances in weather modification, and has resulted in a decrease in public interest in developing and using cloud seeding in the future [44]. Cloud seeding is commonly used at busy airports in the U.S. to reduce hail and fog, but little seeding is implemented to intentionally facilitate higher seasonal rainfall levels.

The primary cost of this alternative is the cost of the \$1 billion funding package itself. As with the desalinization policy alternative, it is estimated that paying a team of 5 project subsidy reviewers and 3 R&D grant reviewers over a period of 3 years will cost roughly \$3 million.

Some of the most significant costs of this alternative involve the potential health impacts on humans and the environmental damages that could result from intensive cloud seeding. The health risks associated with silver iodide, the most widely-used cloud seeding agent, are not well known but it is possible that exposure, inhalation, or ingestion can cause serious health problems which require expensive medical treatment. The impact of silver iodine on soil and air quality and plant and animal life is misunderstood as well. Death and disease of plants and animals can result in a variety of costs, from decreases in tourism and hunting revenue to massive crop failures. Furthermore, soil may be adversely affected by the absorption of silver iodide particles, which may render it useless for growing crops or raising livestock. This would result in significant costs associated with food shortages and land use issues.

One cost of cloud seeding is that it alters the location of natural precipitation. This imposes a cost on regions in which the precipitation would fall naturally, as the clouds in these regions have already been drained of their water where they were seeded. Reductions in rainfall in areas of normally high precipitation can cause crop failures, water shortages, and corresponding increases in the cost of living.

Overall, this policy cost is dominated by the initial funding package, but significant uncertainties related to health and environmental risks are present which are not well understood at this time.

Political Stakeholder Analysis

- Water consumers will support this plan if they are convinced that investment in cloud seeding will ultimately lead to higher water abundance and thus lower water prices.
- Residents of cloud-seeded areas may have mixed opinions. While some residents may welcome the chance for more precipitation on their land, others may oppose the plan because of the risk for contamination of their land by seeding chemicals like silver iodine. Residents who live further downwind from seeded areas are likely to oppose this alternative, as it may result in premature rainfall, leaving other areas void of wet clouds.
- Environmentalists will strongly oppose this alternative because the effects of silver iodine and other seeding chemicals on humans, plants, animals, and soil and air quality have not been studied well. It is possible that chemical seeding can severely damage the environment.
- Water utility companies will support this alternative, because it effectively subsidizes what they already pay for: in California alone, utilities spend about \$5 million per year seeding clouds to increase the snow pack in the Sierra Nevada. More precipitation translates into more water for utilities, which decreases their operating costs.
- Land developers, entrepreneurs, & technologists will support this plan because it allows for the subsidized implementation of new technology, development, and business ventures. Developers of seeding technology can sell it and implement it for utilities, ski resorts, and agricultural organizations.
- Public health advocates will strongly oppose this alternative. The effects of cloud seeding chemicals on humans have hardly been studied, and spending money to implement new seeding technology and infrastructure is too risky when the plan may have disastrous health implications for humans.
- Politicians & states in arid regions are likely to support this plan because it opens up new development and entrepreneurial opportunities while also mitigating water shortages. Politicians in water-abundant regions will oppose the plan because they have nothing to gain by it. They will likely use the potentially negative health implications to fight this alternative.

Do nothing

Although drought is affecting much of the country and experts predict that water shortages will become more severe in the coming decades, enacting national-scale water policy may not be effective, economically feasible, or politically feasible because water abundance varies so greatly by region. Water supply management at the local and state levels may be more effective than federal policy because it provides more flexibility in regulations and practices, which is important when the degree of water scarcity is not uniform across the country. Because extreme water shortages have not yet affected large populations of people, there may not be enough public support to make national water legislation politically feasible at this time. Furthermore, because implementing new technologies or legislation can be extremely expensive, it may not be economically feasible to enact large-scale water policy at this time. It is possible that the efficiencies of technologies like desalinization will improve enough to make these options commercially viable in the future without the need for costly federal subsidies.

This alternative would prevent the federal government from enacting national-scale water management legislation at this time. Although there are no direct costs associated with this alternative, delaying the deployment of water policy until water is more scarce will inevitably be more costly than implementing water policy now. Failure to enact water policy now may also result in catastrophic water shortages in the future, which can be economically crippling, pose health hazards, and cause widespread food shortages.

Political Stakeholder Analysis

- Some water consumers may support this plan because it doesn't result in any immediate water price increases, but others may oppose it because it effectively pushes the water scarcity problem into the future, when water prices will inevitably be higher.
- Residents in water-abundant regions would support this plan, while residents in arid regions with high water prices would not support this policy alternative.
- Environmentalists would oppose this alternative, because it does not alleviate the drainage of important rivers or aquifers which support fragile ecosystems.
- Water utility companies with low operating costs, such as those in very water-abundant regions will support this alternative, while utilities located in water-scarce regions will

oppose this alternative because when water is even more scarce in the future, it will be more costly to implement any of the other alternatives.

- Land developers, entrepreneurs, & technologists would prefer an alternative which exploits a technology such as desalinization or cloud seeding, or a strategy which encourages the development of manufacturing industries. They will not strongly support this alternative.
- Public health advocates in arid regions will oppose this alternative, as it increases the risk that communities in dry areas will run out of water, causing health problems, illnesses, or death.
- Politicians & states in water-abundant regions will strongly support this alternative, because most of the other alternatives will impose some sort of indirect costs on them without providing significant benefits. Political entities in dry areas will oppose this alternative, as waiting to enact legislation until water becomes even more scarce will inevitably cost more than doing it now.

Policy Evaluation

The decision to recommend the adoption of a policy alternative is based on a quantitative analysis of how well that alternative can satisfy a set of n criteria. A numerical weight w_i is assigned to each criterion to represent its relative importance. Finally, the quality of an alternative is characterized by assigning it a score s_i which measures how well it satisfies each i^{th} criterion. A final policy recommendation is made by identifying the alternative with the highest total score, determined by

$$\text{Total Score} = \sum_{i=1}^n s_i w_i.$$

Here, the relative weights are configured so that $\sum_i^n w_i = 1$. The seven policy objectives used in this analysis are effectiveness, cost, political feasibility, technical feasibility, sustainability, equity, and environmental impact.

Since the total score of each policy alternative is strongly influenced by the relative sizes of the weighting terms, it is important to discuss the rationale behind establishing the values assigned to each w_i . For this analysis, since $\sum_i^n w_i = 1$, and there are seven policy criteria

($n = 7$), the average size of each weight is $\overline{w_i} = \frac{1}{7} \approx 0.15$. This means that in a situation where all the policy objectives are deemed equally important, $w_i \approx 0.15$. This value serves as a useful benchmark from which to determine whether a specific criteria should hold a larger or smaller weight than the average weight.

The policy criteria presented here represent important objectives that every desirable policy alternative must satisfy to some degree. Because of the high importance of each objective and the lack of any one objective which is significantly more relevant than the others, the values of the weights are relatively similar and do not deviate by more than 0.5 away from the average weight value $\overline{w_i} = 0.15$.

The first criteria, effectiveness, is the most fundamental and important objective. Adoption of an ineffective policy can often cause more problems than implementing no policy at all. For this reason, effectiveness is weighted as 0.2, which is higher than the average weighting value. Since the entire focus of any environmental policy analysis is to obtain an effective solution to a current or anticipated problem, the objective of effectiveness deserves the highest weighting value.

Nearly as important, and related to effectiveness, are cost, political feasibility, technical feasibility, and sustainability. These criteria receive weighting factors of 0.15 because they are each required for the successful implementation and utilization of the alternatives. Without political feasibility, potential legislation will not be accepted by lawmakers or the public, and without technical feasibility, even a popular policy cannot be successfully implemented. The primary roadblock which limits the adoption of new policies is typically cost, which makes low cost one of the most important policy objectives. The criterion of sustainability is equally important, as one of the primary goals of these alternatives is to effectively manage both the current and future water supply. A policy alternative which is not resilient enough to remain useful and relevant over extended periods of time is unsustainable and ineffective and may require the adoption of costly new policies to supplement it in the future.

Finally, equity and environmental impact each receive weighting values of 0.1. Although these criteria are important, alternatives which are not especially equitable or environmentally-friendly still have the potential to effectively mitigate large-scale fresh water shortages. In other words, it is possible that a policy can be very successful without closely adhering to these criteria. In this analysis, importance is placed on the criteria associated with effectiveness and feasibility of implementation. Since water abundance in the U.S. varies so much by region, legislation which aims to manage water resources at the national level is inherently non-equitable. And although most of the alternatives exhibit some form of negative

	Effectiveness	Cost	Political Feasibility	Technical Feasibility	Sustainability	Equity	Environmental Impact	
Weight	0.2	0.15	0.15	0.15	0.15	0.1	0.1	
Policy Alternative								Total Score
End USDA subsidies during drought	7	3	3	9	8	4	7	5.95
Extend 48C tax credit in wet regions	2	8	7	9	5	4	3	5.45
Investment in desalinization	6	4	7	7	8	5	3	5.90
Investment in cloud seeding	3	6	3	4	6	5	2	4.15
Do nothing	0	3	4	8	0	3	3	2.85

Figure 1: The ability of each policy alternative is scored from 0-10 with regards to how well it meets policy objectives. The objectives are weighted differently based on their perceived relative importance.

environmental impact, the decision to adopt no policy alternatives is also bad for the environment, as current water consumption trends are draining lakes, rivers, and aquifers at unprecedented rates. Since negative environmental impacts and inequality may arise from both policy alternatives and doing nothing, these criteria hold slightly lower weight factors.

An evaluation matrix for determining the final score of each policy alternative is shown in Figure 1. The score of each policy is based on the findings of each analysis and is represented on a scale of 0-10, where 0 corresponds to a total failure of the alternative to meet the objective, and 10 corresponds to a perfect satisfaction of the objective. Summing each of the scores s_i in the evaluation matrix results in highest scores for the first three alternatives in the chart. The lowest scoring alternative is to do nothing, which emphasizes how important it is to enact some sort of large-scale fresh water management policy.

Of the three alternatives which scored highest in the evaluation matrix, extending the 48C tax credit received both the lowest total score and the lowest effectiveness score. This makes it a less powerful policy alternative than some of the others. Although the scores for both investment in desalinization and ending of USDA subsidies were both very close, ending of USDA subsidies is predicted to be more effective at mitigating water shortages, and ultimately achieved a higher total score.

Although ending large agricultural subsidies is not very politically feasible, mainly because of strong lobbying for subsidies from the agricultural industry, the plan is technically feasible because it requires the deployment of no additional technology, government agencies, or large bureaucracies. This policy is sustainable because it can successfully lower water consumption for decades after its adoption, and can be easily altered to meet new challenges or adapt to significant changes in levels of water abundance.

The subsidy policy is the only alternative analyzed here which results in no net negative environmental impact. As farmers raise crops and livestock which consume less water, they leave valuable water in aquifers and reservoirs which is essential for maintaining healthy natural ecosystems in the surrounding regions. The policy also has the highest score for effectiveness, which is based on the fact that it is expected to have a larger impact on water consumption than any of the other alternatives. Finally, although its low score for cost takes into account all the expected costs incurred by farmers and the food industry, enacting the policy would initially result in a net gain in revenue¹ for the U.S. government.

Suggestions from the Experts

During a discussion with three experts, it was suggested that pursuing a hybrid approach to the policy alternatives would be attractive for multiple reasons. First, the three highest-scoring alternatives received similar total scores, between of 5.45 and 5.95 (Figure 1). The similarity in scores suggests that none of the top-scoring policy alternatives are of a significantly higher quality than the others, which implies that no single alternative should be recommended to the detriment of the others. Second, while ending USDA subsidies actually generates revenue for the federal government, extending the 48C tax credit and investing in desalinization both require federal funding. This presents a policy opportunity in which finances generated by reduced agricultural subsidies can be used to directly fund investment in desalinization and the 48C tax credit. It was suggested by the experts that an effective policy option would be to enact all three of these alternatives and link the funding between them, such that the revenue generated from the removal of subsidies would be divided between desalinization investment and extension of the 48C tax credit. This hybrid approach is especially appealing because although it subsidizes new infrastructure, it does not require

¹It is clear that reducing agricultural subsidies cannot create new revenue for the federal government. What is meant here is that a reduction in subsidies will decrease average annual expenditures by the USDA. This decrease in expenditures can be viewed as a net increase in revenue if the budget of the USDA before the policy is implemented is taken as a reference.

any initial federal funding.

The experts also suggested that it is important to analyze how differences in water rights laws across the U.S. relate to the policy alternatives presented. The two primary regulatory systems which currently govern water extraction in the U.S. include riparian rights, which are commonly used in the eastern US and allow property owners to extract water from sources on or adjacent to their property, and prior appropriation rights, which are generally practiced in the western states and give water rights to any party which first puts a body of water to beneficial use. An analysis of the differences between these two water rights systems and how they affect the proposed policy alternatives reveals that the difference in systems has little effect on evaluation of the alternatives. This is mainly due to the fact that none of the alternatives considered in this analysis are directly associated with regulating water usage, extraction, or ownership. Therefore, differences in traditional water rights laws across the U.S. are expected to have little influence on the alternatives presented in this discussion.

Final Policy Recommendation

After a thorough analysis of four policy alternatives and consideration of suggestions by the experts, it is recommended that the U.S. government adopt a policy which incorporates elements of three of the proposed policy alternatives. The recommended policy stipulates that when the USDA designates a county as a primary or contiguous drought disaster country, farmers will receive no USDA subsidies for growing beef, cotton, sheep, pork, chicken, almonds, walnuts, rice, soy, wheat, alfalfa, or corn in that county during the following year. Implementation of this policy will reduce average yearly expenditures of the USDA due to the decrease in amount of annual subsidies issued. This difference in revenue, i.e. the the total savings by the government from implementation of the policy, will be divided up into two funds: one for desalinization investment and one for extension of the 48C clean manufacturing tax credit in water-abundant regions. 80% of the revenue increases resulting from ending USDA subsidies will be used for investment in desalinization. Of these funds, 80% will be issued as subsidies for the construction of new desalinization plants, and 20% will be issued to scientists conducting desalinization research in the form of NSF grants. The remaining 20% of the revenue generated from subsidy cancellation will be used for extension of the 48C tax credit in water-abundant regions as designated by the Department of the Interior. In this way, revenue created by decreasing agricultural subsidies will be used to guarantee improvements in water infrastructure, planning, and management practices.

One potential roadblock to adoption of this hybrid policy approach is that although the funding for the three alternatives is linked, it is associated with unrelated government agencies. Revenue generated from decreases in USDA subsidies will have to be redistributed from the USDA to the Bureau of Reclamation and the NSF for desalinization research, and to the DOE for extension of the 48C tax credit. This untraditional transferring of funds between different agencies may make the hybrid policy approach less politically feasible than adoption of any of the alternatives on their own. However, since the proposed policy is related to water management, it is reasonable for the Bureau of Reclamation to manage revenue transfer between the agencies involved. In the proposed system, the USDA would transfer funds generated by subsidy decreases to the Bureau of Reclamation. The Bureau of Reclamation would then transfer 20% of the total funds to the DOE for use in the 48C tax credit, transfer 16% of the funds to the NSF for use in desalinization grants, and keep the remaining 64% to be issued in the form of subsidies for construction projects related to desalinization. This funding transfer system will avoid the need for the establishment of any new government bureaucracies and will efficiently distribute revenue from where it is generated to where it will be spent.

Conclusion

For the U.S. to avoid robbing its future generations of adequate food, energy, water, and healthy natural ecosystems, it must move towards an economic system which encourages sustainable practices. It is highly inefficient and irresponsible for the federal government to subsidize the production of water-intensive agriculture in regions which commonly experience severe water shortages. Only by growing crops and raising livestock well-suited for arid climates can the agricultural industry responsibly reduce its water consumption and ensure that future generations have access to an adequate amount of fresh water. Since the most effective approach to large-scale water management incorporates elements of both conservation and active water reclamation, a hybrid approach towards water management is recommended here. The recommended policy stipulates that the USDA ends subsidies for water-intensive agriculture in drought disaster areas, and that the revenue saved by the USDA upon adoption of this policy is used for both investment in desalinization and for extension of the 48C clean manufacturing tax credit. This final policy recommendation incorporates elements of all of the high-scoring alternatives analyzed in this study, and requires no up-front funding from the government, which makes it both effective and cost-efficient. The option of enact-

ing no federal-level water policy received the lowest score of all the alternatives presented in this discussion. This fact further emphasizes the urgency and importance with which improvements in national water management should be regarded.

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