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EMERGENT PRECIPITATION ENHANCEMENT TECHNIQUES AND THE RIGHTS TO DEVELOPED WATER

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ABSTRACT: Though the practice of artificial precipitation enhancement has been out of favor in the U.S. for some time, recent developments in environmental computing capabilities and weather modification techniques, in particular, have prompted a review of the state of the science. Emerging computational tools and techniques are presented along with a brief discussion on many of the uncertainties that persist in precipitation enhancement. Because the purpose of weather modification activities is often to augment surface water supplies, a detailed review of water rights associated with such activities is also provided. Quantification of water rights, potential damages to downwind residents in the form of reduced precipitation or changes in aridity levels as well as other environmental disruptions are all potential legal challenges facing would be weather modifiers. Relevant articles of weather modification litigation pertaining to water rights claims are detailed as are some of the possible issues that could be raised were weather modifiers to achieve the capability of confidently diverting specified amounts of atmospheric water. (Note: The discussion on the newly drafted Model State Water Code has been omitted due to administrative changes among the code architects.)
KEY TERMS: Weather modification, cloud seeding, water rights, atmospheric water rights

REVIEW OF EMERGING PRECIPITATION ENHANCEMENT TECHNOLOGIES

Overview

Precipitation formation involves an interrelated chain of events that occur on different spatial and temporal scales. (Bruintjes, 1999) In space these scales range from the microscopic to the continental with each process contributing a critical link to the chain. On the cloud scale, precipitation growth usually takes place through coalescence or ice glaciation processes. Together these and other processes serve to collect cloud water into liquid drops or ice crystals until they are large enough to fall to the ground. Most cloud seeding precipitation enhancement activities seek to increase the efficiency through which cloud water is converted into precipitation. Precipitation efficiency is defined as the ratio of the rate of rain reaching the ground to the cloud base entrainment water flux. Cloud seeding activities have traditionally sought to increase precipitation efficiencies by increasing ice nucleation and collision-coalescence rates. It has also long been acknowledged that changes in cloud- to mesoscale dynamics may increase convective mass fluxes also resulting in increases in precipitation. The following sections briefly describe some of the emergent technologies and techniques used enhance the precipitation process with the intent of increasing ground observed precipitation. The second portion of this paper is devoted to addressing issues raised with regards to water rights to artificially stimulated precipitation.

Emerging Technologies

Over the past few decades the proliferation of high-speed computers has permitted both researchers and operational cloud seeders enhanced analytical capacities. Very high resolution models with sophisticated cloud physics parameterizations can be used to perform theoretical experiments on fundamental cloud processes. The same programs enable operators and managers to perform *a priori* feasibility and optimization studies on cloud seeding activities. The result is that scientists and operators are beginning to have a greater understanding of the precipitation formation process, which may enable them to quantify the effects of cloud seeding activities. These enhanced capacities are beginning to remove some of the uncertainties that have lingered within the field of weather modification for over 50 years since its inception.

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One of these uncertainties has been the fate of cloud seeding materials that are deposited into a qualifying cloud. Atmospheric tracers such as chaff, sulfur hexaflouride (SF_6) and stable isotopes are frequently used to track plume dispersion characteristics. Recent ground-based cloud seeding research has documented the fate of such atmospheric tracers in wintertime orographic precipitation enhancement projects. (e.g. Bruintjes et al., 1995) As measurement accuracy and precision improves it is expected that cloud seeders will begin to reliably trace the paths of the materials they input into clouds as well as track their fate into the larger atmospheric circulation.

Emerging Techniques

Cold Cloud Seeding Model

Cold clouds are considered those whose cloud-top temperatures are between approximately -10° and -12° C. The intent of seeding cold clouds is to stimulate the process of glaciation which is the conversion of supercooled cloud water into ice crystals. This is commonly done by seeding the cloud with certain materials such as dry ice or silver iodide. The addition of these materials into convective clouds with large amounts of supercooled liquid water may not only increase precipitation efficiency through cloud water glaciation, it may also enhance updraft and downdraft convective mass fluxes by releasing heat through phase changes. (Woodley and Rosenfeld, 2000) This process is called dynamical invigoration and has recently been acknowledged as an important mechanism in possibly enhancing precipitation. (Bruintjes, 1999)

Warm Cloud Seeding Model

Warm cloud seeding seeks to increase the precipitation efficiency of clouds whose cloud base temperatures are above 0° C. Hygroscopic nuclei, such as salts, released into the cloud updraft near the cloud base are suspected to reduce time it takes for cloud water to be collected by raindrops and possibly increase precipitation efficiency. Results from recent field experiments in South Africa (Mather et al, 1998), Thailand and Mexico (Bruintjes, 2001) suggest that changes in seeded clouds result in larger rainfall volumes, larger storm areas and longer duration storms. It has also been hypothesized that observed enhanced downdrafts in seeded storms aid in the initiation of secondary convective cells which subsequently evolve to the precipitation stage earlier and more frequently than in unseeded storm cases. (Bigg, 1998)

Trends in Precipitation Enhancement

Precipitation enhancement programs around the world peaked in the 1970's declined in the 1980's and have steadily risen again through the 1990's. Currently, China is the most active country in weather modification with an investment estimated at more than US$100 million for both hail suppression and precipitation enhancement. (Bruintjes, 2001) In the U.S. the last few years have seen an increase in operational weather modification. In the U.S. there are approximately 20 operational precipitation enhancement projects and 25 operational snow pack enhancement projects currently being conducted. Private, local or state "hydro-meteorological" services or agencies support most precipitation enhancement programs. There are currently no federally funded weather modification projects in the U.S. (Note: The U.S. Dept. of Commerce requires full reporting of all intentional weather modification activities within the U.S. and maintains an archive of those activities.)

RIGHTS TO ATMOSPHERIC WATER

Qualifying stipulation

The following sections discuss several issues raised with regards to acquiring rights to atmospheric waters. In the discussion it is strictly assumed that through the use of advanced, scientifically accepted techniques, weather modifiers are capable of quantifying the effect of their activities on the otherwise natural precipitation and atmospheric flow regimes. Lacking such quantitative proof (be it physical or statistical in nature), weather modifiers will never be able to justify claims that they have enhanced precipitation and therefore will likely never be able to claim a right to the "new" water.

Overview

The right to use the water claimed to be developed by weather modifiers seems to have escaped rigorous consideration in weather modification litigation. In the U.S. only a few cases exist which peripherally address the allocation of waters that reside in or fall from the sky (Jones, 1991). Similarly, there is little attention paid to this issue at the state level where only a few states are known to express sovereignty over atmospheric waters. The issue of who can claim ownership to atmospheric water or those waters "unnaturally" derived from the atmospheric water resource reveals an interesting and complex interplay between the limited body of weather modification law and the substantial body of water law. A few authors have attempted to provide discussions on the right to water issue, notably (Davis, 1968, 1974, 1979, 1986; Fischer, 1977; Jones, 1991). This issue will be explored further in this section.

The divisions in water law doctrine in the U.S. provide an appropriate architecture from which to construct a discussion of the allocation of induced precipitation rights. The two primary doctrines of water law are riparian rights and prior appropriation rights. Almost invariably the geographic division of the two doctrines parallels the 100th meridian with most western states subscribing to the prior appropriation doctrine while most eastern states subscribe to the riparian doctrine. Several states possess mixed systems adopting elements of each doctrine where convenient but much of this discussion will focus on the two parent elements.

Riparian Doctrine

Three cases have prominently dealt with the issue of riparian possession in weather modification cases: Slutsky v. New York, S.W. Weather Research v. Runsaville, and Pennsylvania Natural Weather Association v. Blue Ridge Weather Modification Association et al. The decision in Slutsky ascertained that landowners have no right to the clouds and that the sponsor of the seeding activity is entitled to develop the water resource and acquire a legal interest such activities. (Davis, 1974) Even though the decision was made to protect the larger public interest (in this case the water supply for the City of New York), an interpretation of this decision would conclude that developers have superior rights to the atmospheric water resource than do non-developers or those property owners affected by the developer's activities. This precept likens the "rule of capture" doctrine in groundwater law which provides clear incentive to exploit natural resource to their full capacity.

The antithesis to this decision is expressed in the Pennsylvania Natural Weather Assoc. case. There the court ruled "specifically that every land-owner has a property right in the clouds and the water in them." The court went on to qualify this position by adding that weather modification activities undertaken by the government were permissible but that private modifiers have no right "to determine …what his needs are and produce … by artificial means to the prejudice and detriment of his neighbors." (Davis, 1974) In effect, the Pennsylvania court expressed that economic gain was not the highest value to be placed on shared resources and acknowledged that each property owner is entitled to use of the resource so long as the use does not injure other property owners. This would appear to be quite a direct interpretation of riparian water law applied to the atmospheric water resource as opposed to an interpretation of the western prior appropriation doctrine. The court thereby defined the basic resource of atmospheric water as being a property right to be available to all property owners even though the restriction of harvesting the resource may impede some forms of economic development. Such decisions that decree a resource as shared and provide mutual protection to all stakeholders have not been common in the past with the eastern riparian doctrine being the most notable exception.

S.W. Weather Research adopts another element of law in its decision. This is the notion of "natural rights" and that all landowners have a right to "such precipitation as Nature designs to bestow…" Natural rights are also an element of riparian water law based on a strict interpretation that each riparian owner is entitled to the rights to the water that flows adjacent to his or her property "undiminished in quantity and quality." (Sax et al, 1991) Most states have abandoned such a strict interpretation in favor of a reasonable use doctrine which asserts that riparian owners may divert water for use on their property so long as that use is "reasonable" and does not willfully or unjustly damage other riparians. (Note: None of the above judgements required quantification of the effects of the seeding activity, which has been a primary requirement in other liability cases. e.g. Lunsford et al v. United States of America - a suite brought against the Bureau of Reclamation for damages received during the Rapid City, South Dakota flood on June 9, 1972 in which 83 people lost their lives. The Bureau had been conducting cloud seeding activities in the vicinity of the storm that produced the flood.)

Prior Appropriation Doctrine - The Developed Water Principle

In states subscribing to the prior appropriation doctrine there are no cases dealing with a weather modifier's claim to ownership of waters allegedly developed by them. (Jones, 1991) Lacking judicial decisions, some state legislatures have adopted statutes concerning the right to waters developed by weather modification activities. In lieu of moving into a description of state policies, however, it is instructive to determine how artificial precipitation is perceived to be classified under the prior appropriation doctrine. The State of Colorado has forwarded a distinction as to whether or not the water in a surface watercourse is "the water of a natural stream" or if the water is "developed". "Developed" waters as defined by Judge Day in S.E Colorado Water Conservation District v. Shelton Farms are "new waters not previously part of the river system." These waters, by her interpretation, included waters physically imported into a watershed, captured and stored flood waters and waters found within the system which would never have normally reached the river. Most recent casework pertaining to developed waters have emerged from conjunctive use disputes where one party attempts to augment a surface water supply by tapping groundwater reservoirs. In such cases the burden of proof is typically for the augmentor to "prove" that their actions have no influence on the flow regime of the surface watercourse under dispute thereby justifying the claim that the groundwater is not "tributary" to the surface watercourse. (See Williams v. Midway Ranches Property Owners' Association or State Engineer of Colorado v. Castle Meadows)

The question of whether or not waters derived from artificial precipitation are "the waters of natural streams" or "developed" waters is highly important in light of the fact that most streams in the western U.S. are either over-appropriated or nearly fully-appropriated. This means that any new users on a river system are required to prove that the water which they are diverting and putting to beneficial use are truly "developed" waters and would not have been available to the river system had it not been for their efforts. It is generally not disputed in the few existing articles written on the topic (Davis, 1968, 1974, 1979; Fischer, 1977, Weisbecker, 1974; Jones, 1991) that waters attained through weather modification activities are "developed" waters. The difficulty lies in proving the quantity and timing of delivery of water that was "developed." "If the weather modifier can prove that it has actually developed the water it has the most senior right to the newly-developed water." (Jones, 1991) Lacking definitive proof of the measure of increased rainfall, all waters will most likely be considered as part of the natural yield and will be distributed according to established rights. (Dewsup and Jenson, 1977).

Courts will, likely be vigilant in defending current water rights placing the burden of proof solely and conclusively on the weather modifiers. (Fischer, 1977) There is an added difficulty, from a physical standpoint, to the allocation of water developed that will place an onerous burden on weather modifiers. That burden will not only be to quantify the amount of precipitation produced by weather modification activities but determine a precise amount of [said] precipitation that will end up as streamflow, available for diversion and not lost to evapotranspiration or percolation. Another issue that will require detailed quantification is that of the timing of the increased streamflow. Basically, the modifier should be held responsible for determining not only the amount reaching the stream but the time at which such "developed" waters enter the stream. This is imperative to insure current junior users on already over-appropriated systems will not be damaged.

Other General Concerns

Just as natural streams have “instream” uses that derive environmental, recreational and agricultural benefits so do atmospheric waters moving through the atmosphere past a certain location. Although precipitation that reaches the ground is undeniably the most important method of securing atmospheric water it can be effectively argued that ambient humidity levels also play a crucial role in the maintenance of ecosystems and infrastructures of human development. We can therefore speculate on other potential issues pertaining to acquisition of atmospheric water rights by exploring the 100-year plus experience of legal issues that have been raised with regards to acquiring surface water rights. Though the United States has traditionally possessed a dual allocation system of water rights, riparian and prior appropriation, nearly all of the states have adopted an agency permitting system that determines whether or not an applicant will receive, in accordance to the state allocation doctrine, a water right. We will now briefly explore several additional issues that would likely be raised given the situation that a water user wishes to file a claim to water held in the atmosphere or that he or she has “captured” from the atmosphere in the form of artificially induced or enhanced precipitation.

Quantifying the right or diversion

With regards to the prior appropriation doctrine a primary stipulation for acquiring a right is that there be unappropriated water available in the watercourse for diversion. (Sax et al, 1991) Hydrometeorologists quantify the amount of moisture passing over a particular location as the water flux. It would initially seem reasonable to speculate that an atmospheric water user/capturer would merely need to apply for a permit to divert a portion of this flux, either as precipitation or ground based condensation, and put it to some beneficial use. In most appropriation states “one’s water right is measured at the point of diversion” (Sax et al, 1991). However, this requirement is ill-posed with regards to precipitation enhancement. Moisture flux patterns vary rapidly in time, direction and with elevation in the atmosphere. Also, the timing and location of most precipitation generating storms is largely stochastic (though in some regions regional terrain features provide some degree of stationarity). Weather modifiers who seek to tap the atmospheric water resource will therefore need to address the issue of point of diversion, since it has important implications on downstream residents, as different residents are likely to be affected at different times and to varying degrees depending on the nature of the precipitation events. A further complicating factor is that atmospheric flow patterns change on time-scales much more rapidly than do those of surface watercourses. Therefore, if a weather modifier, or even a ground based atmospheric water vapor harvester, were to capture atmospheric water at a specified location for a specified period of time, the affected residents will always be dependent on the atmospheric flow regime and not solely on geographical location. For regulators, it will be extremely difficult to determine the order of atmospheric moisture allocation due to the changing relationships between the direction and magnitude of the moisture flux and the geographical loci of atmospheric water users.

Transfers and Water Markets

The complicating factors associated with quantifying diversions of atmospheric water also serve to complicate the process of transferring such rights or establishing atmospheric water markets. Transfers in surface water rights in western U.S. prior appropriation states have steadily increased over the last several decades as regional economies have transitioned from agriculture to commerce and industry. To foster and perpetuate such change many municipalities and private entities have had to procure water resources by retiring existing agricultural lands and thereby acquire appurtenant water. Should a reliable, quantifiable method of diverting atmospheric water emerge it is plausible that transfers of such rights will occur and also that water markets for atmospheric water rights emerge. However, there are undeniable physical linkages between atmospheric water transport and surface watercourses, such that as the atmospheric water reservoir is tapped, adjustments in existing surface watercourses will occur. The entire system existing surface water rights is based on the concept of "natural" flow regimes in rivers and streams. Thus altering the transport and deposition characters of atmospheric water has the potential to greatly upset the system of appropriations that have been established in many states. Several questions need to be addressed upon consideration of the interplay between surface and atmospheric water rights in a prior appropriation system:

- Will recent diverters of atmospheric water lie outside the lineage of priority of existing surface water diverters even though the capture of atmospheric water may alter regional streamflow patterns?
- Because the movement of water vapor in the atmosphere is transient in both time and space, how will priority between atmospheric water diverters be assigned?
- If an integrated system of appropriation, accounting for both surface and atmospheric diversions, is established, will users be able to transfer diversion rights between surface and atmospheric sources? If so how will this be managed given the increased transience of the atmospheric system?

Consideration of these and other logistical questions reveals the complex interplay between surface and atmospheric waters. Given the physical coupling of the hydrologic system, it unrealistic to consider assigning property rights to atmospheric waters without consideration of how the balance of surface water rights will be tilted.

Transboundary Issues

Atmospheric water, like many surface watercourses transit political boundaries. Thus, just as conflicts have arisen between states based on state-by-state interpretations of surface water allocation measures it is quite likely that any successful weather modification program will face challenges from neighboring states. There has been limited legislative and executive actions taken in the name of defending one state's atmospheric water resources against upwind modification activities. The most notable of these instances is a case described in Davis (1979), where weather modification activities in the upwind states of Oregon and Washington prompted the attorney general of Idaho to threaten litigation in federal court to have the operations enjoined. Only after Washington and Oregon assured Idaho that downwind projects would not be adversely affected was the matter dropped. Alternatively, Colorado and New Mexico have adopted statements in their weather modification statues regarding cross-boarder target areas.

Many authors of scientific publications and/or legal publications have claimed that there is no evidence of decrease precipitation downwind of weather modification activities. (Dennis, 1980) However, Langmuir (1953) conducted one analysis hypothesizing that periodic cloud seeding activities in New Mexico resulted in periodic increases in rainfall as far away as the Mississippi Valley. A more recent review article by Long (2001) has claimed that according to his analyses the downwind effect has universally been to increase precipitation amounts. But just as it has been difficult to quantify the increase in rainfall at a particular location due to cloud seeding it has been similarly difficult to prove any adverse or beneficial effects downwind of seeding operations.

Hypothesized interstate impacts of weather modification are not only limited to relative increases and decreases in local precipitation. Davis (1979), Hemmel and Holderness (1977), and Weisbecker (1974) indicate possible widespread consequences of full-scale seeding operations. These effects include ecosystem shifts, agricultural production changes, changes in electrical power demand, habitat changes, increases in insect and pest incidence, stream temperature changes, changes in timing and amount of snowmelt runoff, increased erosion and increased reservoir sedimentation to name a few. It has been suggested that the issue will likely be dealt with in a similar manner as interstate water issues. There are typically three methods of interstate allocation of surface waters; interstate compact, legislative/congressional enactment and court decisions of equitable apportionment.

Numerous interstate compacts exist on river systems today both in riparian and prior appropriation jurisdictions. The most notable example of a congressional enactment has been the resolution of the long-standing contention between Arizona and California over the lower Colorado River and the implementation of the Central Arizona Project (Sax et al, 1991, pg. 703). Again on the Colorado, the Supreme Court issued its decree of equitable apportionment by dividing the river equally at 7.5 million ac-ft/year between the upper and lower basins. (Sax et al, 1991 pg. 705) It would be expected that as interstate disputes over atmospheric water resources emerge with improvements in technologies, that remediary action will proceed along these courses.

On a larger scale, the United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO) has drafted policy concerning weather modification activities. These recommendations are broad and seek to promote international stability and responsibility while developing atmospheric water resources. In particular the recommendations emphasize notification and disclosure procedures between neighboring nations in efforts to deter subversive or damaging activities.

CONCLUSIONS

It is not yet certain whether the recent advancements in weather modification understanding coupled with increased analytical capabilities will yield new water resource management techniques. Very specific, scientific questions regarding the quantification of effects both within and exterior to operation areas must be answered prior to the widespread application of such techniques. Further, the water rights systems in the U.S. currently do not address atmospheric water in any direct fashion meaning that there is no legal framework from which to determine the rights to the water captured from such activities. There are many complicating factors that prohibit the general application of surface water laws to atmospheric water resources. The issues presented above and others likely to emerge must be addressed in order to insure that an equitable system of apportionment evolves in cooperation with evolving water resources management techniques.

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