Understanding the Economics of Cloud Seeding Projects

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Global warming and population growth are the largest contributing factors to the need to create more water. The impacts vary but typically are greater at lower latitudes (IPCC 2023). The general approach with cloud seeding is to assist clouds in converting the moisture in clouds to become snow (or in the tropics large raindrops) so that in both cases they are heavy enough to fall from the clouds to the ground (ASCE 42-23). Importantly, precipitation in general soon returns to the atmosphere so the water molecules are available to precipitate again and again. Cloud seeding speeds up the process slightly. Cloud seeding can be used for three different purposes: Precipitation enhancement, hail suppression, and fog dispersal. The discussion in this article would apply to all three purposes and most projects of any sort since it is general economic theory. But my focus in this article is on precipitation enhancement.

For a proposed cloud seeding project it is important to know whether or not it is economically justifiable and, if implemented, continues to be economically justified. We know that where conditions are appropriate, cloud seeding can increase the precipitation amount over a desired area. The reason for this is that natural precipitation processes are very inefficient. That is why precipitation occurs in many parts of the world that are many miles from the atmospheric moisture source. The atmosphere can hold a lot of water in its vapor state depending on air temperature but often needs coaxing to release this moisture or convert it to its liquid or solid state. Global Warming increases the ability of the atmosphere to hold moisture. In some cases, it increases the amount of coaxing required to produce precipitation as snow rather than rain. In some cases, rain is equal or more valuable than the water content of snow (SWE) and in some cases, rain is less valuable or even detrimental.

Hydrologic Cycle:

Sometimes Called the Water Cycle.

If I added New Mexico numbers to Figure 1 to help explain the concept, the most reliable number (estimated based on measurements) would be the 100 million acre-feet of precipitation in an average year. Some of that water recharges aquifers. About 2 million acre-feet enters the water supply (supplemented by some inflow from Colorado). Some water evaporates or sustains plant life (transpiration) in remote areas.

What is important is that other than aquifer recharge, all water quickly returns to the atmosphere. Working backwards using my estimates for New Mexico to have 100-

million-acre feet of precipitation in an average year there probably are about 300 million acre-feet of water in clouds and that might mean that 1.5 to 2 billion acre-feet of moisture passes over New Mexico. Whatever the exact numbers are, there is plenty of moisture to work with.

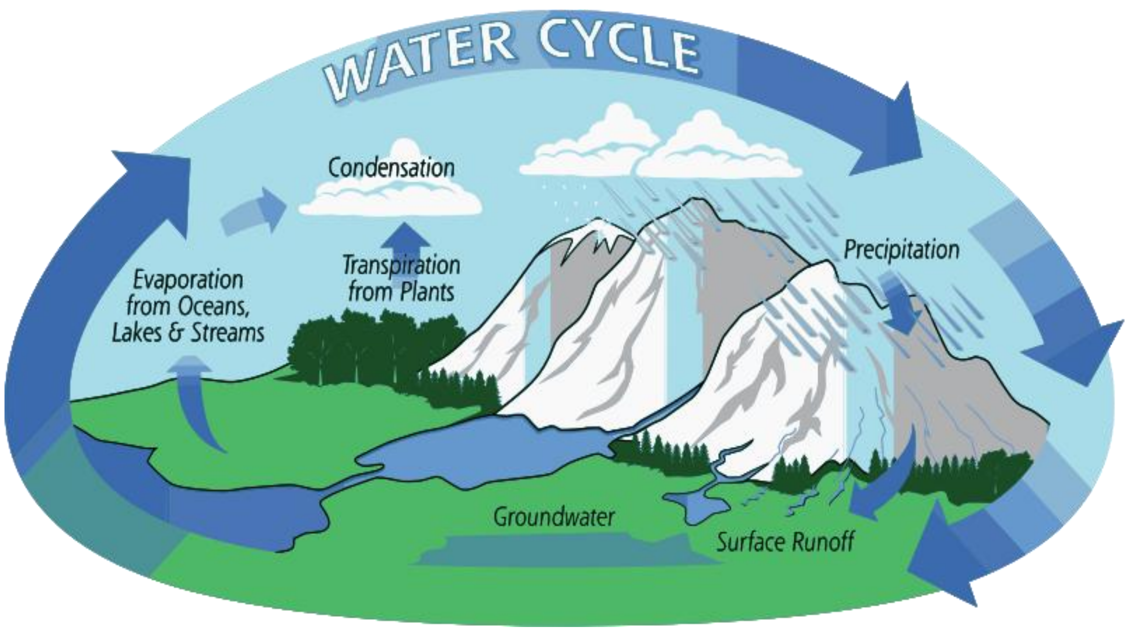

Figure 1. A summary of the Water Cycle. Source: https://openclipart.org/detail/289930/water-cycle

It is important to remember that water is a compound that is almost impossible to destroy. States view the consumption of water in agriculture as a depletion of the state's water resource but evaporation and transpiration of plants in the process of photosynthesis returns the water to the atmosphere where it can precipitate and benefit others in the same state or other states or other nations. This can be repeated over and over again. Precipitation over oceans or water run-off into oceans makes that water unusable (other than, importantly for marine life) unless it is purified. However, the water is not destroyed and can be recovered and used (usually in arid areas such as Israel). Most of our precipitation comes from clouds that form over large bodies of water. So, it is best to view all of this as a cycle. Moisture evaporates from bodies of water or the ground or transpires from plants and enters the atmosphere. Under certain conditions moisture forms clouds. Again, under certain conditions, some of the moisture in clouds precipitates. Precipitation often provides value to people and the environment but mostly (groundwater is an exception that we do not cover in this article) rather quickly returns to the atmosphere to provide the moisture necessary to form more clouds for another round of precipitation.

Using Cloud Seeding to Increase the Velocity of the Hydrologic/Water Cycle and How this Relates to the Economics of Cloud Seeding.

Cloud seeding can speed up the process compared to nature which means that individual water molecules end up providing benefits more times in a year. This process is not widely understood by the general public which sometimes misinterprets the process as robbing Peter to pay Paul. In reality, what happens is that Paul benefits when this might not have happened without cloud seeding. Then it may be someone other than Peter who next benefits from a particular water molecule. In a way, it is analogous to the money supply. For simplicity, consider a situation where printed currency is the only form of money. When the economy is good, a given unit of currency (for example a one-dollar bill) will pass through the hands of more people than when the economy is less good. So, increasing the velocity of money is often a good thing. Within narrow limits, we can increase the velocity of the hydrologic cycle and increase the contribution of water to society.

Economic Analysis of Potential and Operational Cloud Seeding Projects

We know that with cloud seeding we can increase the velocity of the hydrologic cycle and increase the contribution of water to society, but some possible projects and existing projects are more desirable than others. Economics is the discipline where existing and potential projects are compared to prioritizing the application of human effort and capital.

Generally, projects that do not produce more value than their cost are non-economic. I will not address the exceptions to this rule because it devolves into a semantic issue of how one defines value.

But even if the approach produces more value than the cost you still must look at:

- Who benefits and
- Who pays

If the payor and beneficiary are different, there can be problems. In healthcare it is even more difficult because there is usually a third party involved i.e. the insurance company. That creates a very complicated situation which I addressed in a project done by the Diebold Group, Inc for the Robert Wood Johnson Foundation (1990-1994). There are some aspects of that three-way situation with cloud seeding also if government funding is involved.

There can be other factors which complicate the analysis. This is especially pertinent in the U.S. West and Plains States where most U.S. cloud seeding takes place. In most cases, the allocation of the water supply is based on the Priority Doctrine (PD). This means that with cloud seeding, the identity of the direct beneficiary of the additional water is often not known. If more water is available, it goes to those who otherwise would not receive water because their priority would not have been high enough. Priority is usually determined by who diverted and put the water to use first. That may not seem to be an optimal way to do things, but it tends to avoid violence since it is easier to determine who put the water to use first than to agree on which uses are better for society than other uses. There are also limited applications of the Riparian Doctrine where cloud seeding takes place in the United States, and it also can complicate economic analysis in a way that is similar to the Priority Doctrine.

Often there is an exception, namely that precipitation which falls on your land can be used by the landowner or the land owner's designee (typically a renter of the land) as long as the water does not leave the boundaries of the property. If it leaves the property, it typically enters the public water supply, and the Priority Doctrine takes over. However, the specific rules vary by state in the U.S.

A further complication is what are called interstate river compacts which are agreements among states concerning the distribution of the available water supply. The reason this is important concerning cloud seeding is the beneficiary may be in another state. Two important interstate river compacts are the Colorado River Compact and the Rio Grande River Compact. Both also have delivery requirements to Mexico. There are many other interstate river compacts. In general, each one has its own rules. When there is a potential violation of a river compact, the typical response is fallowing of land. Cloud seeding can reduce the amount of land that needs to be fallowed. Who fallows the land might be determined by the priority doctrine but often the taxpayer foots the bill to pay water-rights owners to forgo the use of water. This might not be fair to taxpayers and can create unintended consequences such as dust and erosion.

There are two major categories of beneficiaries:

A. A beneficiary who puts the additional water to beneficial use.

B. A governmental entity that is obligated to deliver water downstream for the benefit of other direct beneficiaries. This can be considered an indirect beneficiary or a facilitator.

Looking at things from a different perspective, the major beneficiaries of water are:

- Farmers
- Ranchers
- Municipalities, especially with regard to their need to deliver water to people and for other uses within a municipality (they could be considered an indirect beneficiary with the ultimate consumer being the direct beneficiary, but they profit from the availability of additional water)
- Ski resorts (they benefit from snow that falls from clouds or water to make snow)
- Hydroelectric facilities to generate electricity.
- Commercial and industrial users who are not getting their water delivered to them by municipalities.
- Recreation
- The environment

Some of the above consume the water and others simply use it and pass it on (hydroelectric and ski resorts). For those who from a legal perspective consume water, that water generally returns to the atmosphere or is treated and reused. So, our use of language in water administration (e.g. consume and deplete) can be somewhat inconsistent with science when it comes to water.

Economic Implications of the Above

In some cases, the payor/funder of a cloud seeding project is also the beneficiary. That is the simple case since the payor can decide if the cost is worth the benefit.

In many cases, the payor of a cloud seeding project is an indirect beneficiary. That is often the case with the interstate river compacts and it is sometimes difficult to get projects funded that assist states in meeting their compact obligations.

The general rule is that cloud seeding is more easily funded when the beneficiaries recognize that they are benefiting from a cloud seeding project. The more direct it is the clearer it is. The more indirect it is the less clear it is. There are ways to deal with this problem but they usually require a high level of effort which may be beyond the ability of many cloud seeding operators and is not guaranteed to result in a contract so many potentially economic projects are never attempted or attempted only when sufficient local interest develops.

Further Discussion

The economics of cloud seeding are complicated. One way of looking at this is that cloud seeding often resembles infrastructure. When a road or bridge is built it usually is not clear exactly who will benefit. Generally, the consideration is whether or not the community or state or the U.S. will benefit. If funded with tax money (or borrowing which usually translates into property taxes) some will have paid for something that does not benefit them but others, and some will benefit many times more than their taxes.

In many cases, cloud seeding is like that. But in some cases, the direct beneficiary can be identified. Perhaps the best example of that would be ski resorts. They benefit from more snow falling from clouds thus having to make less snow. Hydroelectric in some cases is much like the ski resort example. The hydroelectric utility or the users of the generated electricity benefit and they can often recognize the value of cloud seeding to increase the generation of electricity. But on the Colorado River, it is often unclear who would be the beneficiary of more cloud seeding since there are so many different beneficiaries of there being more water in the river. A special case is when the delivery requirements of the interstate river compact are not being met, and the two alternatives are to find more water or use less water.

So, there is often a combination of private and public funding of cloud seeding. As a general rule, the greater the distance of the cloud seeding project from the beneficiaries the more difficult it is to have taxpayers or local government entities see the value to them of such a cloud seeding project.

Secondary and Tertiary Beneficiaries

So far, I have discussed the direct and indirect beneficiaries of cloud seeding. This is based on my knowledge of how cloud seeding projects should be and are usually evaluated in practice. A characteristic of direct and indirect benefits is the usual metric used is the cost of additional water resulting from an existing or proposed cloud seeding project.

Secondary and tertiary benefits are looked at differently. Cloud seeding does have secondary and tertiary impacts, but these are not generally considered because they are more difficult to estimate.

Some of these benefits result from the activity of the cloud seeding project to produce more water. Workers are hired and there are other purchases in the community to support the cloud seeding project. But the larger part of the secondary and tertiary benefits results from putting the additional water to use or avoiding the loss of economic activity from not making up for water deficiencies.

For large projects, the importance of secondary and tertiary benefits becomes increasingly important. But most cloud seeding projects can be justified based on the lower cost of the additional water as compared to other alternatives. I provide this discussion mostly because I think it will be used more often in the future.

IMPLAN or similar software can be utilized for that purpose. There are controversies about the validity of tools like IMPLAN which are based on secondary and tertiary impacts (Keynesian Economics) when an economy is near or close to full employment and the assumptions needed to use a tool like IMPLAN probably exceed the ability of most cloud seeding Operators except if a very large project is involved. But an understanding of the concept can be useful even when not fully utilized.

Secondary impacts include the economic activity of the suppliers to the cloud seeding project and the direct and indirect beneficiaries. Tertiary impacts include the benefits from the activity of all who supply the expanded economic activity of the direct and secondary beneficiaries. More water can increase economic activity or preserve existing economic activity. In many cases it can create or maintain a community where water is central to the existence of the community due to mining or industrial activity based on water availability.

References

IPCC, (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland,184 pp. (doi: 10.59327/IPCC/AR6-9789291691647).

Robert Wood Johnson Foundation Reports (1990 – 1994). Baker Library Special Collections and Archives, Harvard Business School, John Diebold Papers, Series I, Subject files, 1976-2003.

Additional Resources

Weather Modification Association (LINK=https://weathermod.org)

North American Weather Modification Association map of current projects LINK=http://www.nawmc.org/

ASCE EWRI Weather Modification Standards and Guidance Manuals (LINK=https://weathermod.org/wp-content/uploads/2017/05/ASCEorderform.pdf)

***Information on the Author**

Sigmund Silber has a Bachelor's degree in mathematics from Lehigh University (starting initially in their physics program) and a Master's degree in mathematics from NYU. He studied economics at the New School for Social Research in NYC but did not complete the PhD program. Years ago, he taught a graduate level Engineering Economics course at the Polytechnic Institute which is now part of NYU. Mr. Silber is the President of the New Mexico Weather Modification Association and is a member of the ASCE EWRI Weather Modification Standards Committee.