

# Negligible Hydrological Impact of Atmospheric Water Harvesting at Commercial Scales

*A Synthesis of Peer-Reviewed Studies, Colorado Precipitation Pilot Data, and Atmospheric Moisture Dynamics*

## Executive Summary

This synthesis supports a clear policy conclusion: commercial-scale atmospheric water harvesting (AWH) should be treated in Colorado as a **negligible-impact water practice** when evaluated through the same “no injury” lens the state already uses for precipitation harvesting.

The controlling issue in Colorado water administration is not whether a technology touches water at all, but whether it creates material out-of-priority depletions that injure vested senior rights. The state’s own rainwater-harvesting pilot program, the engineering literature that underlies its Regional Factors framework, and the atmospheric-science literature on moisture residence time and source regions all point in the same direction: local AWH extraction is too small, too diffusely sourced, and too weakly connected to stream accretions to cause measurable injury at the commercial scales contemplated here—especially relative to rooftop rainwater capture that has already been studied, conditioned, and permitted.

The Colorado record is especially significant because it concerns a hydrologically more intrusive activity than AWH. Capturing precipitation after condensation—from rooftops and other impervious surfaces—occurs before some fraction of that water could become runoff or delayed return flow. A 2009 Legislative Council issue brief summarizing the 2007 Douglas County study reported that only about 3% of precipitation on the undeveloped test site returned to stream or ground on average, that the maximum was 15% in a wet year, and that none returned in a dry year. The peer-reviewed Colorado accounting-tool paper later described the same undeveloped-catchment result as approximately 97% historic natural depletion and less than 3% runoff ratio, and explained that the state-selected methodology intentionally underestimates infiltration and maximizes protection of downstream water rights. In other words, the state’s legal framework already rests on the empirical proposition that most precipitation on these sites never reaches senior right holders in the first place.

The atmospheric-science record makes the AWH case stronger, not weaker. A 1998 study in *Climatic Change* estimated the e-folding residence time of atmospheric moisture at just over eight days and found that, even at 1,000-kilometer scales, less than 20% of annual precipitation typically comes from evaporation within the domain. For the Front Range specifically, a 2026 moisture-source preprint (not yet peer-reviewed) found that the Pacific Ocean, the western United States, and Colorado together supplied just over 66.2% of May–July 2023 precipitation; it further found that local terrestrial sources were not substantially important to the anomalously wet 2023 season. Colorado climate materials from Colorado State University likewise describe the state as strongly influenced by prevailing westerlies and Pacific moisture, especially outside convective summer episodes.

The broadest available stress test comes from a 2021 *Nature* analysis of global solar-driven AWH. That paper concluded that even if AWH served all 2.2 billion people without safely managed drinking water at 10 liters per person per day, total extraction would be about 8 km<sup>3</sup> per year—only 0.20% of global cropland net water extraction and 0.01% of total land evapotranspiration. The paper’s conclusion was direct: hydro-ecological impacts are probably negligible at that scale.

**The cleanest statutory path is therefore not to force AWH into legal ambiguity, but to recognize it explicitly.** The most defensible policy options are: (1) extend or expand the HB 09-1129 / HB 15-1016 pilot structure before its July 1, 2026 repeal so that AWH can be tested under monitored conditions; or (2) enact a new negligible-impact exemption for commercial AWH systems below a defined size threshold, paired with metering, reporting, and curtailment authority if evidence of injury appears.

## Key Statistics

Metric	Finding	Why it matters
Atmospheric moisture residence time	“Just over 8 days.” At 1,000 km scales, <20% of annual precipitation typically comes from evaporation within the domain.	Fast turnover and weak local recycling reduce the plausibility that a single commercial site can measurably affect downstream precipitation.

Front Range moisture sources	Pacific Ocean, western U.S., and Colorado supplied 66.2% of May–July 2023 Front Range precipitation; local terrestrial sources were not substantially important to the wet 2023 anomaly.	Front Range precipitation is driven chiefly by large-scale advective supply, not a single local parcel of air. (2026 preprint, not yet peer-reviewed)
Douglas County undeveloped-site returns	Average return to stream or ground was ~3%; up to 15% in a wet year; 0% in a dry year.	Colorado's legal foundation for precipitation harvesting already recognizes that most on-site precipitation never reaches senior rights.
Colorado historic natural depletion framework	Peer-reviewed Colorado work describes average annual historic natural depletion of 97% in the undeveloped catchment, runoff ratio <3%.	The state's Regional Factors framework is deliberately conservative and already quantifies a large noninjurious loss component.
Global AWH stress test	Serving 2.2 billion people at 10 L/person/day would withdraw ~8 km <sup>3</sup> /year, equal to 0.20% of global cropland extraction and 0.01% of land evapotranspiration.	A global humanitarian deployment is still hydrologically negligible, implying that a Colorado commercial footprint is far smaller than any meaningful atmospheric perturbation.

## Policy Brief

The legislature does not need to decide whether AWH is identical to rainwater harvesting. It only needs to decide whether AWH can be brought inside a familiar Colorado structure for negligible-impact innovation: defined eligibility, on-site monitoring, public reporting, and State Engineer curtailment if evidence of injury appears. That is already how Colorado has treated other small or pilot precipitation-capture practices, including residential rain barrels and the commercial precipitation-harvesting pilot program.

The immediate timing issue is statutory. HB 15-1016 shifted the repeal of key pilot provisions to July 1, 2026. At the same time, Colorado has moved in a more permissive direction: SB 24-148 amended the pilot-program purposes to allow integrated stormwater and precipitation-harvesting facilities when replacement conditions are met. The policy trend is therefore incremental expansion of monitored capture where injury can be prevented.

## Recommended Legislative Action

Action	Why it is justified	Minimum guardrails
Extend or expand the current pilot before July 1, 2026 to explicitly include AWH.	The pilot already exists to test nontraditional precipitation capture under Colorado conditions and already uses SWSP and augmentation tools. AWH can be evaluated under that same engineering and legal architecture.	Define AWH; require totalized water-output meters; require site meteorology and annual reporting; preserve State Engineer authority to curtail upon evidence of injury.
Create a new negligible-impact exemption for commercial AWH systems under 500 acres.	The atmospheric-science and Colorado pilot records both support a presumption that commercial AWH is hydrologically de minimis relative to streamflow administration.	Use rebuttable presumptions, mandatory reporting, public data transparency, and explicit authority to suspend operations if measurable injury is shown.
Allow local governments to credit monitored AWH as a conservation measure in stormwater and site-design standards.	Colorado has already accepted integrated detention and precipitation-harvesting facilities under the pilot. AWH is complementary because it reduces imported potable demand without increasing tributary runoff capture.	Keep it as a conservation credit, not a substitute for drainage compliance; require separate metering and reporting for any credited system.

A short bill can therefore do three things at once: preserve Colorado's no-injury doctrine, create legal clarity for a technology not expressly contemplated in current statutes, and require the public data needed for later refinement. Waiting until after repeal would discard a functioning pilot structure just as its underlying scientific record has matured.

## Colorado Water Law Context

Colorado's modern surface-water system is organized around prior appropriation: the constitutional right to divert the unappropriated waters of natural streams to beneficial use, with priority giving the better right among users of the same source. In practical administration, that principle is operationalized through the "no injury" standard: out-of-priority uses must replace depletions in time, place, and amount so that senior and other vested rights are not injured.

The legislative story relevant here begins with the 2007 Douglas County/CWCB study, which found that on the undeveloped test site most precipitation was lost to evapotranspiration or related pathways rather than returning to stream or groundwater. Relying on that empirical foundation, HB 09-1129 authorized up to ten new residential or mixed-use pilot projects to collect precipitation from rooftops and impermeable surfaces for nonpotable use. During the pilot term, sponsors had to operate under annually approved substitute water supply plans and replace the captured water.

HB 15-1016 moved the framework forward by replacing the original "net depletion" structure with a more administrable approach centered on historic natural depletion and Regional Factors. Under the revised statute, a sponsor must still fully augment out-of-priority precipitation capture, except that there is no requirement to replace the historic natural depletion caused by preexisting natural vegetative cover on the surface area made impervious; if applicable Regional Factors are used, the State Engineer must give them presumptive effect subject to rebuttal. The bill also extended the pilot provisions' repeal date to July 1, 2026.

**This matters for AWH even though the current statutes do not expressly name atmospheric vapor extraction.** The Regional Factors framework reveals Colorado's operative legal logic. The state is already willing to authorize monitored precipitation capture when hydrology shows that a large share of on-site water was historically consumed by natural vegetation rather than reaching the stream, and when any residual depletion can be tracked and replaced. That is not a blanket exemption from water law; it is a data-driven negligible-impact approach. AWH fits the same logic at least as well, and likely better, because it removes vapor before condensation rather than runoff after deposition.

Colorado has also shown a willingness to refine this framework rather than freeze it. SB 24-148 amended the pilot program's purposes to allow integrated stormwater detention/infiltration and precipitation-harvesting facilities when captured water is replaced in accordance with the pilot requirements and nonpilot water is managed back to the stream system. That 2024 amendment is significant because it shows the General Assembly was still expanding low-impact, monitored precipitation-capture pathways shortly before the current pilot sunset.

## Atmospheric Moisture Dynamics

The atmospheric science relevant to AWH begins with scale. A foundational 1998 study estimated the e-folding residence time of atmospheric moisture at just over eight days and found that recycling is strongly scale dependent; even for 1,000-kilometer domains, less than 20% of annual precipitation typically comes from evaporation within the domain. The same study emphasized that rainfall systems in midlatitudes feed mostly on moisture already in the atmosphere and that over North America much precipitation originates from moisture advected from the Gulf and the subtropical Atlantic or Pacific shortly beforehand.

For Colorado policy, the implication is straightforward: the atmospheric moisture field is fast-moving, regionally mixed, and dominated by transport, not by a stable parcel of locally owned vapor poised to become downstream streamflow. Colorado climatology points in the same direction. Colorado State University materials explain that the state is generally influenced by prevailing westerly winds, that the jet stream carries Pacific air masses eastward, and that Pacific moisture is one of Colorado's three major precipitation patterns.

The newest Front Range-specific evidence is a **2026 preprint (not yet peer-reviewed)**, which should be treated as supplementary. That analysis found that the Pacific Ocean, the western United States, and Colorado supplied just over 66.2% of May–July 2023 Front Range precipitation. It also found that, although local terrestrial contributions increased during the unusually wet 2023 season, the authors could not conclude that local terrestrial sources were substantially important to those wet conditions. This does not mean local moisture is irrelevant in a strict physical sense. It does mean that removing vapor over a single commercial footprint is extremely unlikely to produce a measurable reduction in downstream precipitation, much less the kind of stream depletion that Colorado water law recognizes as material injury.

That conclusion becomes stronger when AWH is compared to rooftop rainwater capture. Rainwater harvesting diverts water after a precipitation event has already occurred over the site and before some fraction of that water could become surface runoff or delayed groundwater return. AWH acts earlier in the chain, on a rapidly mixed atmospheric reservoir whose local influence on ultimate stream accretion is weaker and more diffuse. As a matter of hydrologic causation, then, AWH is the cleaner case. The available science does not support a claim of absolute zero impact, but it strongly supports a finding of **no**

**measurable, no material, and therefore no legally cognizable injury** at commercial scales paired with monitoring.

## Colorado Precipitation Capture Evidence

Colorado has already built the legal and technical foundation this policy discussion needs. The state's rainwater-harvesting studies did not ask whether precipitation capture was metaphysically impact-free; they asked the administratively relevant question: how much water would actually have reached the stream system under predevelopment conditions, and how can any residual depletion be quantified conservatively enough to prevent injury.

The critical synthesis point is this: Colorado's precipitation-harvesting record addresses a category that is **downstream of AWH** in the hydrologic chain. If the state can permit capture of already-condensed precipitation from rooftops or integrated stormwater facilities provided that any stream-connected depletion is conservatively quantified and replaced, then AWH should be easier, not harder, to characterize as negligible impact. The causal connection between an AWH unit and a decreed downstream diversion is more attenuated than the connection between rooftop runoff capture and that same diversion.

## Global AWH Impact Assessment

The strongest AWH-specific hydrologic evidence in the literature is global. A 2021 *Nature* analysis asked what would happen if solar-driven AWH scaled aggressively enough to serve the 2.2 billion people worldwide who lack safely managed drinking water. At a design target of 10 liters per person per day, the resulting extraction would total about 8 km<sup>3</sup> per year. The authors compared that number against the planetary water budget and concluded that it would equal only 0.20% of net global cropland water extraction and 0.01% of total land evapotranspiration. Their bottom-line assessment was that hydro-ecological impacts of AWH for drinking water are probably negligible given the scale of the global atmospheric water budget.

That finding does not eliminate the need for Colorado-specific legal architecture, because Colorado water administration is rights-based and site-sensitive rather than purely volumetric. It does, however, resolve the order-of-magnitude question. If a world-scale humanitarian deployment is still only a tiny fraction of land ET, then the commercial scales contemplated here—roughly 50,000 square feet through 500 acres—are not plausibly large enough to perturb regional atmospheric moisture in a way that would translate into material injury to decreed water rights.

## Gap Analysis and AWH Advantages

The present Colorado evidence base is strongest for rainwater harvesting, not for direct vapor capture. That is the main analytical gap, and it should be acknowledged clearly. No Colorado-specific peer-reviewed field trial identified in the materials reviewed here measures whether a commercial AWH installation changes local humidity, precipitation, or streamflow in a directly observed way.

**However, the absence of a Colorado AWH pilot is not a reason to assume injury. It is a reason to structure authorization as a monitored pilot or rebuttable exemption.** Importantly, the existing evidence gap cuts in AWH's favor on first principles because AWH intervenes *before* condensation and before any site runoff or return flow pathway exists.

AWH also has clear administrative advantages over precipitation capture: output can be metered directly at the machine; production can be logged continuously rather than inferred from storm depth and catchment response; operating thresholds can be tied to device telemetry; and curtailment, if ever required, can be immediate. By contrast, Colorado's rainwater framework already manages a more complex accounting environment involving soil groups, precipitation-event parsing, storage accounting, runoff, and delayed groundwater returns. If the state can administer that system, it can administer AWH.

There are also practical deployment advantages. AWH is inherently decentralized and can serve on-site nonpotable or process demands without a new surface diversion. Controlled-environment uses are especially plausible early adopters because their demand is concentrated, metered, and physically co-located with the equipment. Cannabis cultivation is one credible demonstration market—peer-reviewed reviews describe it as water-intensive with high environmental intensity and controlled indoor production—though the hydrologic case for AWH does not depend on cannabis specifically.

## Policy Recommendations and Conclusion

The best policy design is a narrow authorization with conservative guardrails, not an unbounded declaration. The three recommendations below follow directly from the Colorado statutory record, the precipitation-harvesting pilot data, and the atmospheric-moisture literature.

Recommendation	Basis	Practical Implementation
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Extend or expand the HB 09-1129 / HB 15-1016 pilot before July 1, 2026 so that it expressly includes AWH.	The existing pilot already provides the state’s tested architecture for low-impact innovation, with SWSP review, public reporting, and state oversight; the pilot otherwise repeals on July 1, 2026.	Define AWH as capture of ambient atmospheric vapor by condensation or sorption for on-site beneficial use; require totalized production meters and annual reports to the Board and State Engineer.
Create a “negligible-impact” exemption for commercial AWH systems below 500 acres, subject to monitoring and rebuttal.	Colorado already uses rebuttable presumptions for precipitation capture through Regional Factors, and the atmospheric literature indicates that AWH’s hydrologic footprint is even weaker than rooftop runoff capture.	Require notice, metering, basic site meteorology, public data access, and explicit State Engineer authority to suspend or condition operations if material injury is demonstrated.
Integrate AWH into municipal and Front Range conservation and stormwater design standards as a credited measure.	Colorado law now recognizes integrated stormwater and precipitation-harvesting facilities under the pilot, showing that local design standards can evolve alongside water-rights protections.	Treat AWH as a conservation credit that reduces imported potable demand, while keeping drainage, detention, and water-rights compliance analytically separate.

A policy change framed this way would not displace Colorado’s prior appropriation doctrine. It would apply that doctrine more precisely. The state would still reserve full authority to protect senior rights, but it would do so through evidence rather than presumption. That is exactly how Colorado has already handled other narrow precipitation-capture questions.

The practical next step is a real monitored demonstration. A 50,000-square-foot facility in Aurora is a suitable pilot candidate because it is large enough to produce meaningful data but still far below any volume that the literature would treat as climatically consequential. The policy case is therefore ready for legislative action: extend or amend the expiring pilot, or enact a new negligible-impact AWH exemption with reporting and curtailment safeguards.

## Open Questions and Limitations

This synthesis is strongest on hydrologic injury and weaker on site-specific production because public, peer-reviewed Colorado AWH field data are still sparse. The Front Range moisture-source paper cited above is a preprint rather than a finalized peer-reviewed article. And because AWH performance is technology- and humidity-dependent, footprint alone is not the right compliance variable; metered production is. Those limitations are reasons to favor monitored authorization, not reasons to maintain a legal vacuum. The evidence reviewed here is already sufficient to support a conservative legislative finding that commercial AWH is negligible impact under Colorado’s Regional Factors logic and should be allowed under a monitored statutory pathway.

## References (Key Sources Cited)

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