Groundwater Management Frameworks from Other Western States

This document identifies and reviews groundwater governance models employed in other states, focusing on elements of those models that could potentially inform place-based or statewide management strategies to address specific groundwater challenges in New Mexico.

This document organizes lessons from other western states around five elements of sustainable groundwater management. This framework is grounded in hydrologic systems thinking, field tested governance tools, and the lived experience of people facing groundwater challenges. These five pillars are:

1. **Science, Data, and Modeling -** to better understand conditions, enable informed decisions, build trust, and support planning.

2. **Governance & Investment -** to support locally-driven solutions with state alignment and support.

3. **Holistic Basin Management Goals -** to move beyond crisis response toward shared future conditions, by defining desired future hydrologic conditions considering community, economic, and environmental values.

4. **Integrated Groundwater-Surface Water Management -** to reflect the reality of surface-groundwater connections and interconnected values across New Mexico's basins.

5. **Flexible, Adaptable Management Tools -** to support transitions in water use and adapt to declining supplies.

It's important to highlight that no state has ideal groundwater management everywhere, and in fact, significant areas of groundwater depletion and notable resulting water quantity and quality challenges continue to occur in practically every state across the western United States. Yet, the tools and lessons referenced here have helped address urgent challenges, and in many situations have helped to turn general trends from depletion to balance. While each state has different geology, history, legal frameworks, and cultural nuances, many of the basic drivers and remedy options related to groundwater depletion are similar. Accordingly, thoughtful consideration of how other states' tools and lessons might be adapted for New Mexico's unique legal, cultural, and physical setting is an important step to facilitate the rapid progress that New Mexico's groundwater challenge deserves.

1. Case Studies Illustrating Science, Data, and Modeling

Sustainable groundwater management begins with a shared understanding of hydrologic conditions, aquifer behavior, and the implications of current and future pumping. Across the West, states vary in the strength, scale, and integration of their data and modeling systems. Technical uncertainty - especially around groundwater-surface water interaction - can limit the enforceability of plans, slow permitting decisions, and reduce trust among stakeholders. By contrast, well-supported science and data systems offer a foundation for more transparent, durable, and adaptive decision-making.

Texas

Texas has built a highly decentralized groundwater management system in which local Groundwater Conservation Districts (GCDs) and regional Groundwater Management Areas (GMAs) are tasked with defining and achieving long-term aquifer goals, known as Desired Future Conditions (DFCs). To support this, the state has invested in a system of Groundwater Availability Models (GAMs) administered by the Texas Water Development Board (TWDB) - a key tool that helps local managers understand hydrologic conditions and explore management scenarios. These models play an essential role in supporting science-based decision-making, but limitations remain. Budget cuts in the early 2010s hindered the

program, and although funding has since been restored, challenges persist: GAMs are often too coarse for local district use, many GCDs lack funding or technical capacity to develop tailored models, and groundwater-surface water interactions remain poorly integrated in state modeling efforts. While the state has provided vital technical support, there is still uneven ability to fully realize locally defined objectives, adaptive tools, and informed engagement - especially in regions with limited resources or contested management goals.

As noted above, no state has perfect groundwater management across the board, and significant depletion and ecological degradation continue in many Texas aquifers. Nevertheless, investment in groundwater science and modeling has helped many local entities clarify their water futures and develop better-informed policies. Across the West, including in New Mexico, the need for accessible, well-funded, and integrated groundwater science is foundational to equitable and sustainable management. Texas's approach highlights the importance of state-level support and investment - particularly in large, decentralized systems - where local entities may not have the resources to manage science-intensive tasks on their own.

This case study focuses on the role of scientific information, modeling infrastructure, and funding support in enabling effective groundwater management - particularly for states like New Mexico, where capacity gaps and hydrologic complexity present real barriers to sustainability planning.

Case Study: The role of adequate funding for groundwater science

Managing groundwater to meet sustainability or other goals requires that good science be readily available to managers and users. Detailed, functional and accurate groundwater models are a key element of that science (in addition to regular and widespread monitoring). But these models can be complex, expensive and often require significant expertise to develop and use properly.

The Texas Water Development Board (TWDB) provides groundwater availability modeling services to the state's system of local groundwater conservation districts (GCDs). These models are also used in the development of aquifer wide "desired future conditions" by Groundwater Management Areas (GMAs). GCDs and GMAs can request various scenario runs from TWDB to explore management options. According to TWDB, "[g]roundwater availability models include comprehensive information on each aquifer, such as recharge (amount of water entering the aquifer); geology and how that conveys into the framework of the model; rivers, lakes, and springs; water levels; aquifer properties; and pumping. Each model is calibrated to ensure that the models can reasonably reproduce past water levels and groundwater flows."

In 2011, the state legislature cut the groundwater modeling by more than half, even as it increased the planning responsibilities of GCDs and GMAs. Advocates for the GCDs and for better groundwater management have since convinced the legislature to restore much of that funding, which has greatly improved its services to the GCDs and GMAs.

While this state service is valuable, the large-scale Groundwater Availability Models (GAMs) are frequently insufficient for GCD-level management decisions. Some Texas GCDs have sufficient funding through taxing authority or other revenue sources to conduct their own modeling, but many do not.

Another issue is whether the GAMs are adequately linked to surface water availability models, accurately representing the interconnection between groundwater and surface water. An analysis by EDF found that the linkage between the state's groundwater and surface water models leaves considerable room

for improvement. This is particularly problematic for GMAs that are looking to establish "desired future conditions" that protect spring and stream flows, as they are authorized to do under Sec. 36.108(d) of the Texas Water Code. As EDF's analysis has noted:

"The lack of funding for GW/SW data and modeling limitations as it relates to GW/SW interactions impact GCDs' ability to properly consider GW/SW interactions in the DFC process and to ensure more sustainable use of water from these sources via conjunctive use."

In summary, adequate funding for groundwater science is an important factor in sustaining an effective groundwater management system. The funding should be sufficient for both aquifer-wide models and down-scaled models that are needed for more localized decision-making. Moreover, integration of groundwater and surface water models will be important to protecting springs and surface water flows from groundwater over-pumping.

2. Governance and Investment – Supporting Locally Driven, State-Supported Management

Groundwater governance in arid states increasingly reflects the need to balance local knowledge and participation with statewide consistency, legal accountability, and technical support. Many successful frameworks empower basin-scale planning by local entities while establishing clear authority for the state to intervene when necessary. Long-term effectiveness depends not only on legal structure but on whether local institutions are sufficiently resourced to implement plans, adapt to change, and enforce regulations.

Nevada

Nevada's groundwater management framework reflects a hybrid approach that blends local engagement with firm state oversight - emphasizing both community-based planning and enforceable legal backstops. The most "red alert" management designation in Nevada is the Critical Management Area (CMA) designation, a regulatory mechanism triggered when long-term groundwater withdrawals exceed the estimated perennial yield, Nevada's benchmark for sustainable use. Once designated, a basin enters a 10-year window for local stakeholders to collaboratively develop a Groundwater Management Plan (GMP). If no plan is adopted and approved within that period, the State Engineer is required by statute to impose priority-based curtailments, which can be abrupt and economically disruptive.

The CMA structure incentivizes early local action while maintaining the authority for state intervention. It supports locally defined goals, flexible tools such as shares-based allocations, and a reliance on science-driven planning and water use monitoring. The case of Diamond Valley illustrates how these elements can come together to stabilize a severely overdrawn aquifer through stakeholder collaboration and innovation.

Nevada's broader groundwater governance also addresses conjunctive management - the coordinated regulation of groundwater and surface water - through approaches like that used in the Walker River Basin, where curtailments are triggered by unmet streamflow targets. There, the State Engineer has implemented adaptive, flow-based curtailment orders aimed at protecting senior surface water rights and supporting ecological restoration in Walker Lake. This case demonstrates how a clearly defined priority system, backed by monitoring data and judicial support, can serve as a foundation for integrated water management in complex, water-scarce systems.

It's important to highlight that no state has ideal groundwater management everywhere, and in fact, significant areas of groundwater depletion and notable resulting water quantity and quality challenges continue to occur in practically every state across the U.S. West. Yet, the tools and lessons referenced here have helped to address urgent challenges, and in many situations have helped to turn the general trends from depletion to balance. While each state has different geology, history, legal frameworks, and cultural nuances, many of the basic drivers and contributing factors related to groundwater depletion - and the accompanying remedy options - are similar. Accordingly, thoughtful consideration of where appropriate tools and lessons from other states might be adapted and deployed for New Mexico's unique legal, cultural, and physical setting is an important consideration to facilitate the rapid progress that New Mexico's groundwater challenge deserves.

The following two case studies from Nevada - Diamond Valley and the Walker River Basin - illustrate how state-driven designation mechanisms, community planning, and enforcement of water rights priorities can combine to support more sustainable groundwater outcomes in basins with different hydrologic and governance dynamics.

Case Study: The role of local engagement in managing overuse

Nevada's Critical Management Areas (CMAs) offer a model for addressing groundwater overuse that balance local control and state support and oversight. CMAs are established when groundwater pumping in a basin consistently exceeds available supplies, triggering a process that allows local stakeholders to develop a Groundwater Management Plan (GMP) to restore balance. This approach prioritizes community-driven solutions, avoiding abrupt state-enforced curtailments while maintaining oversight by the State Engineer. If local plans fail to materialize within 10 years, the State Engineer enforces curtailment based on water rights priorities.

A key feature of Nevada's framework is its flexibility, allowing local water users to design tailored solutions within the state's legal and hydrological parameters. This model aligns well with New Mexico's need for adaptive and participatory management of its groundwater basins, many of which face similar challenges of overuse and declining aquifers. The CMA structure balances local autonomy with state oversight, creating a phased approach to address varying levels of groundwater stress.

The case of Diamond Valley illustrates the practical application of this model. After being designated a CMA in 2015 due to significant groundwater declines, local stakeholders developed a GMP that introduced a shares-based water allocation system. This system is reducing consumptive use over time, emphasizing socio-economic stability, and avoiding abrupt disruptions to the community. In a pivotal 2022 ruling, the Nevada Supreme Court upheld the GMP, affirming its legality and providing a significant precedent for innovative groundwater management approaches. This decision solidifies the viability of locally-developed plans within the CMA framework and underscores the importance of **balancing** hydrological sustainability with economic and social resilience. Diamond Valley's experience demonstrates how tools like water banking, flexible allocations, and robust monitoring systems can effectively stabilize aquifers while maintaining community welfare.

Nevada's governance model also highlights the role of the State Engineer in both facilitating local planning and ensuring compliance. The perennial yield concept underpins management goals, and the State Engineer supports local efforts with technical resources, monitoring, and enforcement capabilities. This dual structure of local planning and state oversight provides a model for integrating hydrological,

economic, and social considerations, advancing sustainable groundwater management without undermining local economies or water rights systems.

Case Study: Walker River Basin Curtailment and Priority-Based Management

The Walker River Basin in western Nevada presents a case where the Nevada State Engineer implemented priority-based curtailments to manage groundwater depletion and its impacts on surface flows. This case highlights the challenges of conjunctive management, particularly in a system where groundwater pumping has long supplemented surface water diversions but has increasingly affected river flows. To address these impacts, Nevada established river flow targets, which, when unmet, triggered curtailments based on water rights priorities, with an initial focus on supplemental irrigation wells used by surface water right holders.

The Walker River originates in California's Sierra Nevada mountains and flows through western Nevada, terminating in Walker Lake, a terminal saline lake that has suffered from dramatic declines due to upstream water use. Irrigated agriculture has long been the dominant water use in the basin, with rights to both surface water from the Walker River and groundwater pumping to supplement surface supplies, particularly during drought years. However, decades of increased groundwater use began to affect river flows, threatening both senior surface water rights and environmental resources.

Nevada's State Engineer recognized the need for a regulatory approach that linked groundwater and surface water management, particularly to protect senior water rights and stabilize flows to Walker Lake. In response, the state developed a system that established flow-based triggers, which, when not met, initiated curtailments according to the state's priority system.

In 2018, the Nevada State Engineer issued a curtailment order for groundwater use in the Walker River Basin, structured as follows:

- Establishment of River Flow Targets: The State Engineer set minimum flow requirements for the Walker River at specific measurement points, designed to monitor surface water availability for senior rights holders and ecological needs, including the restoration of Walker Lake (Nev. State Engineer, 2018 Curtailment Order).
- Priority-Based Curtailment System: If river flows fell below target levels, curtailments were implemented based on the state's prior appropriation doctrine, with junior users curtailed before senior users (Nev. Rev. Stat. § 533.370).
- Focus on Supplemental Wells: The first category of water rights to be curtailed included supplemental irrigation wells, which had been historically used by surface water right holders to offset shortages. Since these wells were junior in priority and contributed to overall depletion of river flows, they were prioritized for restriction before surface water cuts were imposed (Walker River Irrigation Dist. v. State Engineer, 473 P.3d 402 (Nev. 2020)).
- Phased Curtailments and Monitoring: Curtailments were implemented progressively, with junior supplemental well users being required to cease pumping first, followed by successively senior groundwater users if flow targets continued to be unmet (Nev. State Engineer, 2018 Curtailment Order).

The implementation of priority-based groundwater curtailments in the Walker River Basin was not without controversy:

- Impact on Agricultural Operations: Farmers who relied on both surface and supplemental groundwater struggled to maintain irrigation schedules, particularly during drought years when surface water allocations were already reduced.
- Legal Disputes Over Conjunctive Management: Some irrigators challenged the curtailment order, arguing that groundwater and surface water should be managed as separate resources. However, the Nevada Supreme Court upheld the State Engineer's authority to regulate groundwater pumping that affected river flows (Walker River Irrigation Dist., 473 P.3d at 408).
- Concerns Over Walker Lake Restoration Goals: The use of curtailments to maintain river flows to Walker Lake was controversial, as agricultural users viewed it as an environmental-driven policy that disproportionately impacted farming communities. The state countered that maintaining Walker River flows was essential for compact compliance, ecosystem health, and senior water rights protection (Nev. Div. of Water Res., 2021 Report on Walker River Management).
- Adaptive Management Needs: The flow-based triggers required continuous monitoring and adjustments, leading to concerns over …

The Walker River Basin case offers key insights for New Mexico's groundwater management, particularly in basins where groundwater and surface water are interconnected:

- Flow-Based Triggers Can Provide a Flexible Approach: By using flow targets as a basis for curtailment, Nevada developed a dynamic system that adjusts restrictions based on real-time hydrological conditions rather than rigid annual allocations.
- Supplemental Wells Can Be a Strategic Regulatory Focus: Targeting supplemental irrigation wells first helped balance the needs of both surface and groundwater users while prioritizing the protection of senior rights. New Mexico could consider similar approaches in basins where surface water shortages are exacerbated by supplemental pumping.
- Legal Clarity on Conjunctive Management is Critical: The Walker River litigation underscores the importance of clear legal frameworks for linking surface and groundwater rights. New Mexico, which has recognized the connectivity of these resources in key basins, could strengthen its legal and enforcement mechanisms.
- Adaptive Management is Necessary: The Walker River case demonstrates that priority-based curtailments require ongoing monitoring, stakeholder engagement, and adjustments to ensure effectiveness and fairness.

Nevada's Walker River Basin curtailment system represents an innovative approach to managing groundwater in a conjunctive-use system, balancing legal priorities, environmental goals, and agricultural demands. The case highlights the complexity of priority-based groundwater restrictions, particularly when they are linked to flow-based triggers and supplemental groundwater pumping. While the policy has faced resistance, it provides a valuable model for states like New Mexico that seek to manage groundwater in relation to surface water impacts, protect senior rights, and develop more adaptive management frameworks.

The Walker River Basin case provides valuable lessons for policymakers considering priority-based groundwater curtailments, offering insights into the interplay between legal priorities, hydrological realities, and economic consequences in water-scarce regions.

Oregon

Oregon's groundwater management approach exemplifies a tiered, adaptive framework that tailors regulation and planning to basin-specific conditions across the state. With 22 designated groundwater administrative areas - including Critical Groundwater Areas (CGWAs), withdrawn basins, and limited-use zones - Oregon combines statewide data collection and monitoring with localized stakeholder engagement. The system supports the development of locally defined groundwater objectives, while providing regulatory backstops such as full withdrawals and curtailments when necessary. Tools like Oregon's Drought-CREP program further illustrate how flexible and adaptive tools can be deployed alongside voluntary conservation incentives, especially in regions like the Harney Basin, where aquifer declines have been severe. Oregon's emphasis on stakeholder-led planning and coordinated funding mechanisms highlights the importance of community participation and shared decision-making, even as broader enforcement authority remains with the state.

As in other western states, Oregon's groundwater framework is not uniformly effective, and serious depletion, administrative complexity, and uneven implementation persist, especially in agriculturally intensive regions. Nonetheless, Oregon offers valuable lessons in how a state can use graduated management levels, legal and administrative scaffolding, and cross-agency coordination to balance local flexibility with the need for long-term aquifer stability. For New Mexico, where several basins face similar conditions of overuse and fragmented governance, Oregon's tiered model - particularly its balance between local planning autonomy and state-defined fallback actions - may offer a useful template for both interim and long-term management solutions.

This case study focuses on locally led planning efforts within a flexible regulatory framework, and illustrates how adaptive management, incentive-based conservation, and cross-level collaboration can be used to support groundwater sustainability in hydrologically stressed regions.

Case Study: Groundwater Management in Oregon - A Tiered Approach to Tailored Management

Oregon's groundwater management framework is structured around a system of 22 designated groundwater administrative areas with varying levels of restriction. This approach combines statewide regulation with targeted local initiatives, offering a flexible model for addressing groundwater challenges in diverse hydrological and socio-economic contexts.

Oregon's Levels of Groundwater Management:

- Groundwater Limited/Classified Areas: These areas are subject to specific limitations or classifications that restrict water use. These restrictions can include time-limited permits or specific requirements for well construction to ensure sustainable use and protect senior rights.
- Areas Withdrawn from Further Appropriation: Some regions are closed to new water rights appropriations entirely to prevent further stress on groundwater supplies. These areas may also include well construction requirements designed to protect existing water users.
- Critical Groundwater Areas (CGWAs): Declared when groundwater resources are critically overdrawn, CGWAs impose strict restrictions to stabilize aquifers. These may include pumping reductions, limitations on new permits, or revocation of existing permits to protect the resource and senior water rights.

Staff from the Oregon Water Resources Department (OWRD) monitor these areas to ensure that the implemented restrictions are effectively protecting groundwater resources and the rights of existing users. The state's adaptive approach allows for localized management strategies to address unique regional needs.

The Harney Basin in southeastern Oregon provides a case study of localized groundwater management within the state's broader framework. The Harney Basin is currently withdrawn from further groundwater and surface water appropriation, but has not yet been designated a Critical Groundwater Area, to provide time for the locally-led planning effort to offer solutions before state-level restrictions are imposed. Historically reliant on groundwater for agricultural irrigation, the region has experienced severe declines in water levels due to overpumping. A place-based planning effort is underway in the Harney Basin, involving diverse solutions to address groundwater overuse. These include:

- Voluntary water rights buy-backs to reduce groundwater pumping.
- Transitioning irrigated lands to less water-intensive uses, including habitat restoration.
- Investments in water-efficient technologies and infrastructure.
- Enhanced monitoring and data collection to support adaptive management decisions.

By integrating local stakeholder input and leveraging state support, the Harney Basin's approach demonstrates how Oregon's tiered groundwater management framework can adapt to address regional needs while promoting long-term sustainability.

3. Holistic Basin Management Goals - Defining Desired Future Hydrologic Conditions

Many basins in New Mexico are managed only by decline. Without agreed-upon sustainability goals, decisions are often reactive and fragmented. A foundational step toward sustainable groundwater management is the articulation of basin-specific goals that reflect the physical limits of the resource as well as the values and priorities of local communities. These goals can take the form of thresholds for drawdown, aquifer storage, spring flow, or "safe yield," and should account for economic, environmental, and cultural uses of water. Setting these targets transparently - and aligning management actions accordingly - can help clarify regulatory intent, help communities make informed tradeoffs, guide investments, and build shared accountability.

California

California's approach to groundwater management reflects a dynamic and evolving legal landscape - one that combines high-level state mandates with basin-level governance flexibility and long-standing adjudicated systems. The 2014 passage of the Sustainable Groundwater Management Act (SGMA) marked a watershed moment, establishing for the first time a statewide mandate to manage aquifers sustainably. SGMA created a multi-tiered planning process grounded in local control: newly formed Groundwater Sustainability Agencies (GSAs) are tasked with developing Groundwater Sustainability Plans (GSPs), backed by monitoring requirements and technical standards. While SGMA formalized a statewide framework, its 25-year implementation window - stretching to 2040 - has also enabled significant new groundwater development in some of California's most water-stressed regions. This delayed enforcement, combined with investor-driven land conversions and deep-well drilling in the Central Valley, has led to worsening aquifer depletion, subsidence, and equity concerns.

At the same time, California also offers instructive examples of earlier, locally tailored groundwater solutions. In the Mojave Basin, a court-led adjudication and stakeholder-negotiated settlement created a durable groundwater management framework well before SGMA's enactment. This basin-level approach introduced production allowances, market-based water transfers, and adaptive conjunctive management of surface and groundwater resources. The Mojave Water Agency, acting as Watermaster, oversees implementation in coordination with local advisory committees and environmental agencies. The result is an integrated management system that balances water supply reliability, habitat protection, and long-term sustainability across a complex and urbanizing region.

These two distinct approaches - the statewide planning and accountability framework under SGMA, and the judicially led, stakeholder-driven settlement in the Mojave Basin - highlight the range of institutional pathways California has pursued to confront groundwater depletion. Each model offers key insights: SGMA underscores the importance of legislative action and long-term planning across jurisdictions, while the Mojave Basin demonstrates the potential of negotiated, flexible frameworks to address complex, interconnected groundwater and surface water challenges. Yet both cases also reveal the limits of even well-designed systems when enforcement lags, economic incentives encourage overuse, or environmental safeguards are politically contested.

It's important to highlight that no state has ideal groundwater management everywhere, and in fact, significant areas of groundwater depletion and water quantity and quality challenges continue to occur in practically every state across the U.S. West. Yet, the tools and lessons referenced here have helped to address urgent challenges, and in many situations have helped to turn the general trends from depletion to balance. While each state has different geology, history, legal frameworks, and cultural nuances, many of the basic drivers and contributing factors related to groundwater depletion - and the accompanying remedy options - are similar. Accordingly, thoughtful consideration of where appropriate tools and lessons from other states might be adapted and deployed for New Mexico's unique legal, cultural, and physical setting is an important consideration to facilitate the rapid progress that New Mexico's groundwater challenge deserves.

The following two case studies from California - SGMA and the Mojave Basin settlement - illustrate how both regulatory and adjudicated systems can support basin-level groundwater recovery, and how gaps in enforcement, incentives, or equity considerations can significantly influence real-world outcomes.

Case Study: The Mojave Basin Settlement - A Unique Path to Innovative, Integrated Groundwater Management

California's Mojave Basin provides a unique model of groundwater management that pre-dates the regulatory frameworks introduced by the Sustainable Groundwater Management Act (SGMA). Instead, it emerged from a judicial adjudication process that culminated in a cooperative settlement agreement. This framework utilizes phased reductions to address groundwater overuse over time, temporary and permanent water market mechanisms to accommodate changes in use, and it integrates surface water management and environmental considerations. Although this case study follows a unique initiation path, components of the management structure provide models for tools that could potentially be integrated into state policy frameworks.

The Mojave Water Agency was established in 1960 to address regional water challenges, including the need for imported water from the California State Water Project. Decades of groundwater overdraft led to declining river flows, riparian habitat degradation, and mounting tensions among water users. In

1990, the City of Barstow initiated litigation against upstream users, claiming their overuse was depleting downstream resources. This triggered a full basin adjudication involving over 1,000 parties.

By 1993, stakeholders negotiated a stipulated judgment that defined groundwater rights, established a management framework, and addressed the basin's overdraft issues. Following legal challenges and appeals, the settlement was finalized in 2002, offering a comprehensive management solution for the region's interconnected groundwater and surface water resources.

Several factors informed the settlement and management approach:

- Development and changes in types of water use. Groundwater use had been shifting from agriculture to municipal and industrial uses in the region, with many fast-growing ex-urban/suburban municipal communities. The solution needed to find options to reduce or replace groundwater use while supporting continuing growth and economic development was important.
- Conjunctive management issues. Upstream groundwater pumping impacted surface flows in the Mojave River, which is largely a subterranean stream but flows above ground in a portion of the middle basin. The solution needed to address impacts of groundwater pumping on interconnected subsurface and surface flows.
- Special status species. The Mojave River and its tributaries support important habitat that sustain aquatic and terrestrial wildlife and plant species, including rare, threatened, and endangered species. Management activities needed to avoid, minimize, or mitigate impacts to biological resources.
- Minimal users. Due to the significant number of parties involved (initially over 6,000 parties were included – anyone in the basin with a well), the court dismissed de minimus water users pumping less than 10 acre-feet per year to streamline the process and minimize the cost of administering the judgment.
- Availability of imported water. Mojave Water Agency was originally established to claim water rights from the State Water Project. Development of enhanced facilities to bring imported **water** into the Basin was a critical component of reducing overdraft over time while providing another source of supply to avoid negative impacts to producers or biological resources.

Under the settlement, the Mojave Water Agency serves as the Watermaster, overseeing groundwater management and implementing the adjudication terms. The framework includes subarea advisory committees, elected by local water users, to ensure representation and input in management decisions. Governance also involves coordination with the California Department of Fish and Wildlife to protect biological resources.

The settlement's overarching goal is to maximize the beneficial use of the basin's water resources while balancing hydrological, environmental, and economic needs. Specific objectives include:

- Reducing groundwater overdraft through ramp-down schedules for pumping allowances.
- Ensuring surface flows for downstream users and riparian habitat.
- Supporting the region's transition from agricultural to municipal and industrial water use.
- Integrating environmental protections, including biological resource mitigation.

The Mojave Basin framework employs several innovative tools to address groundwater overuse:

- Production Allowances: Historical groundwater users were allotted Base Annual Production Allowances, subject to annual reductions to reach sustainable use levels. New users must acquire allowances through temporary or permanent transfers.
- Water Markets: Users can trade production allowances, offering flexibility for development and changes in types of use over time.
- Monitoring and Adaptive Management: An extensive well network tracks groundwater levels, surface flows, and environmental impacts, informing management decisions.
- Recharge and Augmentation Projects: Imported water, stormwater infiltration, and treated effluent recharge are utilized to replenish aquifers and support groundwater-dependent ecosystems.
- Biological Resource Protections: A trust fund and mitigation measures safeguard riparian habitats and species.

The Mojave Basin settlement's flexible, integrated, and market-oriented approach offers a tailored solution for a region characterized by diverse water needs and hydrological complexities. By integrating groundwater and surface water management, protecting environmental resources, and enabling voluntary transactions, the settlement addresses overdraft while accommodating economic growth.

Case Study: The SGMA Milestone and a Cautionary Tale

California's landmark Sustainable Groundwater Management Act (SGMA) was passed in 2014 and codified at Cal. Water Code §§ 10720-10738. This hard-won legislative victory was a huge step forward in charting a path toward sustainable groundwater use in California. See, Tina Cannon Leahy, Desperate Times Call for Sensible Measures: The Making of the California Sustainable Groundwater Management Act, 9 Golden Gate U. Envtl. L. J. 5 (2015-2016). Among SGMA's signature achievements are aquifer-specific planning, local control over specific regulatory requirements for SGMA compliance, and statutory timelines for accomplishing the multi-step process of setting up new, local groundwater management entities and plans. This all takes time to accomplish, and SGMA set a time horizon of 25 years between the effective date of the Act and its enforceable groundwater sustainability requirements.

SGMA requires balancing recharge and extraction in all state aquifers by 2040, with detailed statutory directives setting intermediate planning and process milestones to be achieved along the way. By 2017, local governmental entities had to create or identify "groundwater sustainability agencies," (GSAs) responsible for implementing SGMA in their area. Cal. Water Code §§ 10723, 10727. GSAs were tasked with creating groundwater sustainability plans (GSPs) no later than 2022, and by 2020 for high-risk groundwater areas. Cal. Water Code § 10720.7. The GSPs do not require sustainable levels of groundwater pumping until 2040. This 25-year lead time between SGMA's passage in 2014 and its regulatory sustainability mandates in 2040 was a political necessity to achieve the consensus needed for passage of the Act. This 25-year gap has allowed new groundwater pumping in key areas of California, putting even more pressure on already-declining aquifers.

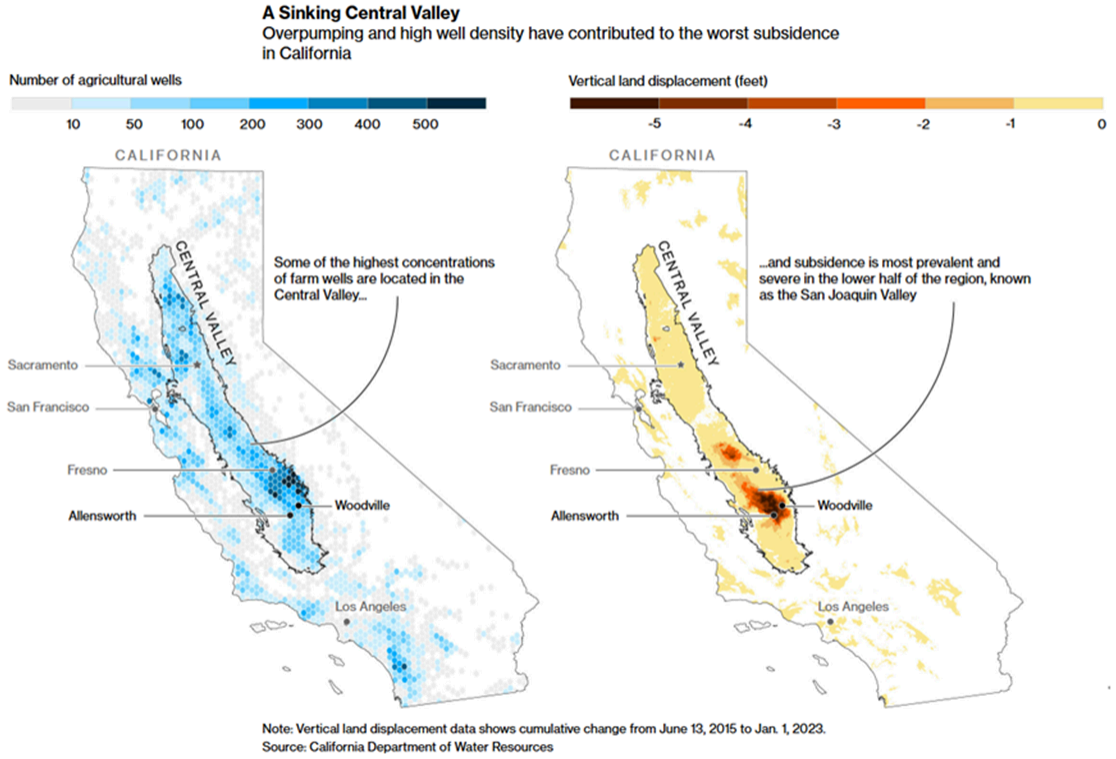
California's Central Valley has the highest concentration of groundwater wells serving irrigated farms and orchards in the state. The Central Valley also has the highest concentration of subsidence areas, with the most severe subsidence in the southern half of the region, known as the San Joaquin Valley. See, Fig. 1, below, data from Cal. Dept. of Water Res. Depicted in Figure 1 is the cumulative subsidence in California since the passage of SGMA, showing the severity of subsidence in the San Joaquin Valley.

Bloomberg Green did a series of investigative reporting articles on private investors and their command of water resources. The first in the series examined how some of the country's largest investors are drilling some of the deepest groundwater wells in the San Joaquin Valley after SGMA's passage: Peter Waldman, Sindjua Rangarajan, and Mark Chediak, Groundwater Goldrush: Banks, pension funds and insurers have been turning California's scarce water into enormous profits, leaving people with less to drink, Bloomberg Green (April 11, 2023).

This reporting found that from 2014 through August 2022, at least 70 new wells had been drilled on land owned or managed by the biggest institutional investors in California nuts, including Gladstone Land Corporation (a publicly traded real estate investment trust (REIT)), Hancock Agricultural Investment Group, and TIAA. The majority of these wells have been drilled to at least 1,000 feet and are capable of extracting three times more water than the median agricultural well. The cost of these deep wells, upwards of $350,000, also puts them out of reach of smaller producers or low-income communities. These and other institutional investors were driving the conversion of row-crop farms into orchards: since 2014, California's almond acreage increased by 50%, while pistachio orchards, which can withstand drier conditions than almonds, expanded by almost 90%. Id.

Bloomberg Green's reporting obtained Hancock's 2022 report to pension fund managers under Florida's public-records law. Hancock warned its investors that it expects California's groundwater regulations under SGMA to limit well-water production by 75% in the area of one of its 1,800-acre pistachio orchards - but not until 2040. The "strong current cash flows," reported Hancock, justified the investment even if it anticipates "fallowing two-thirds of its acres by 2040." Id.

Cumulative subsidence since SGMA's passage, Fig. 1, reproduced from: Peter Waldman, Sindjua Rangarajan, and Mark Chediak, Groundwater Goldrush: Banks, pension funds and insurers have been turning California's scarce water into enormous profits, leaving people with less to drink, Bloomberg Green (April 11, 2023).



Arizona

Arizona's Active Management Areas (AMAs) represent one of the most ambitious groundwater regulatory frameworks in the western U.S., created to manage groundwater use in the state's most populous and water-stressed regions. Rooted in the 1980 Groundwater Management Act, the AMA system provides locally tailored goals, such as "safe yield" in Phoenix and Tucson or planned depletion in agriculturally focused regions like Pinal and Douglas. The framework incorporates flexible management tools - including conservation requirements, recharge credits, and groundwater withdrawal permits - and has contributed to notable improvements in municipal efficiency and aquifer recharge in some areas. However, persistent challenges remain: data limitations, enforcement gaps, and Arizona's bifurcated legal system for surface and groundwater have limited the effectiveness of the program in achieving true long-term sustainability. The Santa Cruz AMA, with its focus on groundwater-surface water interactions, stands out for its integrative goals, but also highlights how difficult it can be to implement and enforce such complex, interdisciplinary objectives.

It's important to emphasize that no state has solved groundwater management universally or permanently, and even in Arizona, where institutional infrastructure is strong, groundwater depletion continues in many AMA subregions. Yet, Arizona's AMAs offer important lessons about the power - and limits - of formal regulation, flexible regional planning, and goal-based management. For New Mexico, which has not yet implemented basin-scale regulatory goals or withdrawal limits, Arizona's experience illustrates both the potential benefits of clear, enforceable management objectives and the importance of sustained investment in implementation, monitoring, and adaptation.

This case study focuses on the role of locally defined groundwater basin objectives and flexible management tools, while also surfacing the importance of science, data, and implementation capacity in achieving meaningful outcomes in arid-region groundwater systems.

Case Study: Active Management Areas and the Challenges of Achieving Sustainable Groundwater Use

Arizona's Active Management Areas (AMAs) represent a regulatory framework for groundwater management designed to address the unique challenges of a desert state with limited water resources. Established under the 1980 Groundwater Management Act, AMAs are regions where groundwater usage is heavily regulated to prevent overuse. The primary goal in most AMAs is achieving "safe yield," defined as balancing groundwater withdrawals with natural and artificial recharge. However, some AMAs, such as the Pinal and Douglas AMAs, have goals that essentially allow for planned depletion, reflecting different local priorities and hydrological realities.

An interesting example is the Santa Cruz AMA, which recognizes the international nature of the river basin and surface water-groundwater interactions. This focus is unique in Arizona AMAs and acknowledges the critical relationship between groundwater and the Santa Cruz River, aiming to maintain riparian areas and surface flows. However, despite its innovative approach, the Santa Cruz AMA has faced challenges in implementation. Its policies have proven difficult to administer, and its impact on groundwater sustainability has been limited, offering lessons on the complexities of managing interconnected water systems, particularly in Arizona's bifurcated legal systems between surface water and groundwater management.

The Phoenix AMA exemplifies the broader successes and struggles of Arizona's approach to groundwater management. With a safe yield goal set for 2025, the Phoenix AMA has made strides in conservation, recharge, and water reuse. Municipalities have implemented progressive water-saving measures, and agricultural water use has decreased over time. However, the AMA still faces significant barriers to achieving its objectives. Rapid urbanization, reliance on groundwater during droughts and/or Colorado River shortages, and limited enforcement mechanisms for noncompliance have hindered progress. Lack of clear data on aquifer conditions and water use have also created obstacles for transparent and effective management.

Arizona's governance structure for AMAs demonstrates the importance of tailored management goals based on regional hydrological and socio-economic conditions. While the Phoenix AMA aims for safe yield, the Pinal AMA's planned depletion reflects its uncertain transition from agricultural to municipal uses over time. The Douglas AMA's version of planned depletion reflects the importance of its agricultural water uses and very limited recharge opportunities. This flexibility allows for localized approaches but also underscores the need for robust data collection and adaptive management to address evolving water challenges.

Despite the AMAs' innovative design, long-term groundwater sustainability remains elusive in many areas. The challenges faced by AMAs, such as localized areas of impact within AMAs, insufficient enforcement, inadequate data, and the difficulty of integrating surface and groundwater management, provide important insights for other states in arid regions developing groundwater management solutions.

4. Groundwater-Surface Water Integration and Flow-Based Management

In the West's arid regions where hydrologic connectivity drives ecological function and water supply reliability, some states have adopted regulatory frameworks that explicitly integrate surface and groundwater management. These models demonstrate how legal triggers, flow protections, and mitigation requirements can structure more responsive and enforceable systems - particularly in basins where pumping affects surface water rights, ecosystem flows, or compact obligations.

Montana

Montana's groundwater management in the western part of the state is uniquely shaped by the legal and hydrologic connections between groundwater and surface water. In designated closed basins - where new surface water rights are no longer issued - Montana law now requires groundwater applicants to demonstrate whether proposed pumping will deplete connected surface flows and to mitigate those impacts if they affect existing rights. This approach puts scientific analysis (hydrogeologic assessments) and impact-based permitting at the core of decision-making, even as limited state modeling infrastructure places the burden of proof on applicants. The state's framework establishes basin-specific permitting triggers and mitigation obligations that reflect a finite-resource perspective, though enforcement capacity and permit-exempt well oversight remain significant challenges. The system advances locally relevant water management objectives in ecologically and politically sensitive basins, yet statewide implementation is uneven, and residential development pressures continue to strain the system.

As noted above, no state has ideal groundwater management everywhere, and significant areas of groundwater depletion and resulting water quantity and quality challenges persist across the U.S. West. However, tools like those in Montana's closed basins have helped protect senior surface water rights, preserve ecological flows, and reduce groundwater-surface water disconnection in key river systems. While each state's legal, hydrologic, and institutional context is different, many of the underlying drivers of groundwater decline - and the policy tools used to respond - are similar. For New Mexico, which faces growing pressures to manage connected groundwater and surface water use more explicitly, Montana's experience highlights the potential of integrated permitting, impact-based mitigation, and protective default rules.

This case study focuses primarily on information and understanding of groundwater conditions to support decision-making, as well as locally defined objectives and mitigation-based management tools that aim to prevent injury to rivers and senior surface water rights.

Case Study: Groundwater Management Driven by Impacts to River and Stream Flows

The twin forces of extended drought and rapid population growth have brought water scarcity issues to the forefront of water policy debates in Montana. Irrigated agriculture in Montana largely relies on surface water right claims, with senior claims dating back to the 1860's. Since the 1960's, however, Montana irrigators have been relying on groundwater pumping to bring new acres into irrigated production. Even though the Montana legislature closed the sprawling Upper Missouri River Basin - encompassing much of the western half of the state - to new surface water rights due to over-appropriation in 1991, the state had still granted 432 new permits to pump groundwater and irrigate more than 6,500 new acres since the basin closure was legislatively enacted. Irrigators in Montana's Smith River basin (part of the state's Upper Missouri River Basin) requested that their County

Conservation District ask the state to conduct a hydrologic study of the basin due to low river and stream flows and concerns about increasing water scarcity.

Montana's Department of Natural Resources and Conservation (DNRC) began collecting data in 2000, and the study was progressing well until a staff hydrologist wrote in an internal, departmental memo in March, 2001, that "it can be stated with certainty that ground water withdrawals have created impacts to surface flow of the Smith River." The DNRC's Director abruptly ordered a stop to the hydrologic study and prohibited his staff from relying on the study's findings in relation to the 15 new groundwater permit applications then-pending before the agency. The summer of 2001 brought drought conditions so severe that portions of the Smith River ran dry and wild trout died in droves. Irrigators and anglers alike looked beyond drought for answers. Nine ranchers, three fishing outfitters, and the conservation organization Montana Trout Unlimited filed an action in state district court, alleging that the DNRC was failing to follow its own laws by processing new groundwater pumping permits despite the state's own evidence that the pumping was injuring senior, surface-water rights. The Montana Supreme Court ultimately agreed and issued a moratorium on the state's ability to issue new groundwater permits.

The Montana Supreme Court's moratorium forced the Montana Legislature into action, and at the 11th hour of the 2007 session, the Montana Legislature passed House Bill 831 providing new groundwater management directives within Montana's closed river basins. Montana's groundwater management framework in western Montana is distinct in that it is designed around protecting surface flows in rivers and streams, rather than estimates of rates of aquifer recharge or groundwater depletion. Some of its key elements are:

- Groundwater permit applicant must carry out a hydrogeologic assessment. An application for new groundwater pumping in a closed basin must conduct a hydrogeologic assessment to "predict whether the proposed [groundwater pumping] . . . will result in a net depletion of surface water." Mont. Code Ann. § 85-2-360(1). If a "net depletion" to surface flows is determined, then the applicant must develop a plan to address the depletion to surface flows if there is also adverse effect on an existing water right claim. The elements of the hydrogeologic assessment are detailed in Mont. Code Ann. § 85-2-361.
- Mitigation plan to address surface flow depletions required. By requiring new groundwater pumping to offset its impacts to surface flows, the Montana laws essentially set up a water exchange, where retirement of a senior surface water use is needed to acquire a new groundwater pumping permit. See, Mont. Code Ann. § 85-2-362, "Aquifer recharge or mitigation plans in closed basins."
- Treats water as a finite resource. Montana's unique combination of basin closure laws and its groundwater management in these closed basins of western Montana means that water is managed as a finite resource, whether surface or ground water. In most cases, in order to acquire a new groundwater pumping permit, an existing surface water right must be dedicated to offset the groundwater pumping in a volume of equal to the estimated new, consumptive use. See, Mont. Code Ann. § 85-2-363, "Process for combining decisions on groundwater permit applications in closed basins." Rather than looking to the availability of groundwater as a function of aquifer levels or recharge rate, Montana's laws look to the aquifer's connection to stream and river flows and to make the determination of water availability.

The Limitations of Montana's Approach.

The groundwater management legislation passed in 2007 to govern western Montana's closed basins was Montana's first effort to proactively regulate groundwater withdrawals. In the almost two decades since its passage, its primary limitations have come into focus and subsequent litigation and legislative efforts have tried to address them. These are some of the key lessons learned:

- Patchwork of groundwater data and burden on the applicant. The applicant for a new groundwater pumping permit has the burden of collecting and analyzing data that predicts and estimates the impact on surface water flows of the proposed groundwater pumping and its consumptive water use. The State of Montana does not have a groundwater model for each closed basin that an applicant could access. This means that it is a time-intensive, expensive process to apply for a new groundwater permit.
- A surface water right claim change application is also required. Another hurdle a groundwater pumping permit applicant faces is a change application to change an surface-water irrigation water right claim to a mitigation purpose through the Montana DNRC's water right change process. See, Mont. Code Ann. §§ 85-2-361-362. The DNRC's water right change process can be slow, time-consuming, and difficult, leading to recommendations for reform and legislative studies to accomplish it.
- No state enforcement or agency capacity to prevent illegal groundwater use. The only enforcement mechanism requiring compliance with Montana's groundwater regulation is when proof of a valid groundwater pumping permit is required by another entity - typically through a County's subdivision review process, for example. When no other permit or review process requires proof of a new, valid groundwater pumping permit, standard practice is to hire an out-of-state well driller not subject to Montana's well registry requirements and pump without a permit.
- Permit-exempt groundwater well "loophole" for residential development. Many states struggle with the proliferation of individual, groundwater wells for domestic and lawn and garden use. As in many western states, in Montana these so-called "exempt" or individual wells are exempt from groundwater permitting requirements. In Montana, they are limited to a pumping rate of 35 gallons per minute and an annual volume limitation of 10 acre-feet/year. See, Mont. Code Ann. § 85-2-306(3), "Exceptions to Permit Requirements."

As the time and expense to obtain a groundwater pumping permit increased, so did the reliance on "exempt" wells for new, residential development outside of municipalities. As the proliferation of "exempt" well subdivisions increased, senior water right holders challenged the state's management of individual wells and won another Montana Supreme Court victory for senior water rights in Clark Fork Coalition v. Tubbs, 2016 MT 229, 384 Mont. 503, 380 P.3d 771 (2016). In this case, the Court reinstated a 1987 agency rule that prohibited the use of exempt wells when they pulled water from the "same source" to be a "combined appropriation" that would exceed the annual volume limit of 10 acre-feet/year. Id. at ¶¶ 32-40, 384 Mont. 517-519.

Recent litigation following up on the Montana Supreme Court's 2016 exempt well decision found that dividing subdivision development into phases to avoid triggering the "combined appropriation" limitation violated the reinstated 1987 rule. Upper Missouri Waterkeeper v. Broadwater County, No. BDV-2022-38, slip op. at 79 (Mont. 1st Dist., Feb. 14, 2024). The court noted that Montana has an estimated 191,000 "exempt" wells, with an allowed, total appropriation of 1.9 million acre-feet/year of groundwater, concluding: "While each exempt well might appropriate "only a de minimus quantity of water," Clark Fork, 24, they are starting to add up." Id. at 84-85. The 2025 Montana Legislature is considering exempt well legislation developed by a legislative working group in which four of the state's

fastest-growing counties would be off limits to exempt wells, while allowing subdivisions of up to 24 lots on exempt wells in other areas of the state. Amanda Eggert, Groundwater debate surfaces in Legislature, Bozeman Daily Chronicle, Jan. 31, 2025, at A1, A5.

5. Flexible, Adaptable Management Tools - Incentives, Markets, and Enforcement Mechanisms

Groundwater sustainability in arid regions often depends not just on clear rules, but on the availability of tools that help users adapt to new limits. Flexibility is especially important in overdrawn basins where steep reductions in groundwater pumping may be needed to prevent aquifer collapse, legal non-compliance, or ecosystem harm. States have deployed a mix of incentives, market mechanisms, and enforceable curtailments to support transitions in groundwater use while maintaining economic viability and protecting senior rights.

California

Case Study: Markets, Transfers, and Recharge in California's Mojave Basin

California's Mojave Basin provides a unique model of groundwater management that pre-dates the regulatory frameworks introduced by the Sustainable Groundwater Management Act (SGMA). Instead, it emerged from a judicial adjudication process that culminated in a cooperative settlement agreement. The Mojave's settlement agreement is discussed above, at pages 14-15. The Mojave Basin framework employs several innovative tools to address groundwater overuse:

- Production Allowances: Historical groundwater users were allotted Base Annual Production Allowances, subject to annual reductions to reach sustainable use levels. New users must acquire allowances through temporary or permanent transfers.
- Water Markets: Users can trade production allowances, offering flexibility for development and changes in types of use over time.
- Monitoring and Adaptive Management: An extensive well network tracks groundwater levels, surface flows, and environmental impacts, informing management decisions.
- Recharge and Augmentation Projects: Imported water, stormwater infiltration, and treated effluent recharge are utilized to replenish aquifers and support groundwater-dependent ecosystems.
- Biological Resource Protections: A trust fund and mitigation measures safeguard riparian habitats and species.

The Mojave Basin settlement's flexible, integrated, and market-oriented approach offers a tailored solution for a region characterized by diverse water needs and hydrological complexities. By integrating groundwater and surface water management, protecting environmental resources, and enabling voluntary transactions, the settlement addresses overdraft while accommodating economic growth.

Nevada

Case Study: Addressing Overappropriation With Nevada's Water Rights Buy-Back Program

To mitigate groundwater overuse in regions like Diamond Valley, Nevada has implemented the Voluntary Water Rights Retirement Program. This initiative utilizes $15 million in federal funds from the American Rescue Plan Act, allocated through the Nevada Department of Conservation and Natural Resources, to purchase and permanently retire groundwater rights from willing sellers. The program is available statewide, prioritizing overpumped basins, with water rights in Diamond Valley valued at $800 per acre-foot. The initiative has seen significant interest, with more applicants than available funding, indicating a strong willingness among landowners to participate in efforts to restore groundwater balance.

Oregon

Case Study: Addressing Over-Appropriation with the Drought-CREP Program in Oregon's Harney Basin

The Harney Basin in southeastern Oregon provides a case study of localized groundwater management within the state's broader framework. The Harney Basin is currently withdrawn from further groundwater and surface water appropriation, but has not yet been designated a Critical Groundwater Area, to provide time for the locally-led planning effort to offer solutions before state-level restrictions are imposed. Historically reliant on groundwater for agricultural irrigation, the region has experienced severe declines in water levels due to overpumping. A place-based planning effort is underway in the Harney Basin, involving diverse solutions to address groundwater overuse. These include:

- Voluntary water rights buy-backs to reduce groundwater pumping.
- Transitioning irrigated lands to less water-intensive uses, including habitat restoration.
- Investments in water-efficient technologies and infrastructure.
- Enhanced monitoring and data collection to support adaptive management decisions.

By integrating local stakeholder input and leveraging state support, the Harney Basin's approach demonstrates how Oregon's tiered groundwater management framework can adapt to address regional needs while promoting long-term sustainability.

The Drought- Conservation Reserve Enhancement Program (CREP), established under the federal Farm Bill and administered by the Farm Services Agency (FSA), provides financial incentives for landowners to retire groundwater pumping rights and transition irrigated lands into conservation uses, such as restoring native vegetation. In the Harney Basin, this program has been utilized as one tool among many to address groundwater overuse and aquifer declines.

How It Works:

- Landowners voluntarily enroll in the program and receive payments based on the value of their retired groundwater rights. In the Harney Basin, the State of Oregon negotiated an increase in the FSA's standard compensation rate, in part because Oregon provided incentives beyond the minimum state "match" required to the federal payments.
- Enrolled lands are converted to conservation uses for 15 years, reducing groundwater demand and enhancing ecological conditions. In the Harney Basin, irrigators and the State of Oregon negotiated the ability to convert irrigated ground to non-irrigated hay pasture for continued grazing use, providing important flexibility to producers receiving CREP incentive payments to reduce groundwater pumping.

Challenges and Limitations:

- Insufficient Compensation: Payment rates under Drought-CREP often fall short of making producers whole, especially in areas with high-value agricultural production.
- Administrative Complexity: Successful implementation requires extensive coordination between federal, state, and local agencies, as well as ongoing outreach to landowners.
- Short-Term Focus: While effective in reducing groundwater use temporarily, Drought-CREP must be integrated with long-term strategies to ensure sustainability.

Key to Success: Drought-CREP is most effective when supported by strong state leadership and matching funds to enhance compensation rates and streamline implementation. In the Harney Basin, it has been a valuable component of broader efforts to address groundwater challenges, highlighting the need for comprehensive, multi-faceted solutions.

Colorado

Case Study: Mandatory Pumping Curtailments in Colorado's Republican River

Colorado's experience in the Republican River Basin illustrates how legal obligations and enforcement of water rights priorities can drive significant groundwater management decisions, especially in areas where interstate compacts govern surface water availability. The state's groundwater governance framework integrates priority-based curtailment, state-led enforcement, and voluntary retirement programs - tools used in response to Colorado's compact obligations to Kansas and Nebraska. While data, modeling, and augmentation infrastructure support these decisions, ongoing challenges with monitoring accuracy and economic impact mitigation remain. This case highlights the importance of a clear legal framework, state agency capacity, and tools for both mitigation and enforcement. Unlike more participatory or locally driven models, Colorado's system in this basin relies heavily on top-down curtailments and a strong role for the State Engineer, with limited room for local discretion.

As in other western states, Colorado continues to face substantial groundwater challenges despite a robust legal and administrative structure. The Republican River Basin case demonstrates how interconnected surface and groundwater systems require clear rules, enforcement authority, and technical support to avoid interstate conflict and to comply with legal obligations. For New Mexico, which is similarly bound by the Rio Grande Compact and faces pressure to manage groundwater depletions affecting surface flows, Colorado's experience underscores the value of enforceable authority, compact compliance planning, and voluntary mitigation programs, alongside the political and economic tradeoffs such measures entail.

This case study focuses on priority-based groundwater curtailments and the role of state enforcement in achieving compliance, offering relevant lessons for compact-affected regions with limited water supplies and interconnected resource systems.

The Republican River Basin in eastern Colorado exemplifies a case where groundwater pumping has been curtailed based on water rights priorities, driven by both state law and interstate compact obligations. The basin is governed by the Republican River Compact, an agreement between Colorado, Kansas, and Nebraska signed in 1942 to allocate water from the Republican River and its tributaries. Over time, groundwater pumping in Colorado contributed to depletions in surface water flows, violating the

terms of the compact and triggering legal and administrative actions that resulted in mandatory curtailments for junior water users.

The Republican River Basin extends across Colorado, Kansas, and Nebraska, supporting agriculture, municipal use, and natural ecosystems. Groundwater pumping from the High Plains Aquifer has provided a crucial source of water for irrigation in eastern Colorado, but it also affects surface water flows into Kansas and Nebraska.

By the late 20th century, Kansas argued that Colorado and Nebraska were overusing the river's water, particularly through groundwater pumping that depleted streamflows. A series of legal disputes followed, culminating in a 2003 U.S. Supreme Court ruling that confirmed Colorado was out of compliance with the compact. Kansas v. Nebraska & Colorado, 538 U.S. 720 (2003). In response, Colorado implemented measures to reduce groundwater pumping, including voluntary retirements and a pipeline project to deliver water to Kansas. However, compact compliance remained a challenge, leading to the need for stricter curtailments.

In 2020, the Colorado Division of Water Resources (DWR) issued a mandatory curtailment order on certain junior groundwater wells in the Republican River Basin. Colo. Div. of Water Res., 2020 Republican River Basin Curtailment Order. The order primarily affected wells with priority dates after 1975, which were deemed out of priority based on surface water depletion impacts and compact obligations. Under Colorado's prior appropriation system - often summarized as "first in time, first in right" - these junior rights holders were required to stop pumping to protect senior surface water rights and to comply with the compact.

Key elements of the curtailment process included:

- Identification of priority dates for shutoffs: Any groundwater wells with post-1975 priority dates were subject to curtailment if they were determined to be contributing to surface water depletions.
- Enforcement by the State Engineer: The curtailments were enforced by the Colorado State Engineer, who has statutory authority to administer water rights and ensure compliance with both state law and interstate agreements. Colo. Rev. Stat. § 37-92-102 (2021).
- Voluntary retirement and mitigation programs: Alongside mandatory curtailments, the Republican River Water Conservation District (RRWCD) has operated voluntary groundwater retirement programs, offering financial incentives to irrigators willing to cease pumping permanently. Republican River Water Conservation Dist., Compact Compliance & Groundwater Management Strategies (2022).
- Pipeline augmentation project: The Colorado Compact Compliance Pipeline, completed in 2012, delivers groundwater directly to the North Fork of the Republican River to help offset depletions and reduce curtailment pressures. However, this has not fully resolved compact compliance issues. Id.

While the 2020 curtailments were a necessary step for compact compliance, they sparked legal and economic challenges:

- Economic Impact on Agriculture: Eastern Colorado is heavily reliant on groundwater for irrigation. The loss of junior groundwater rights significantly affected farming operations, leading to reduced crop yields and land value declines. Jones & Smith, Groundwater Curtailments and Agricultural Impacts in Eastern Colorado, Water Policy Journal, 2021.

- Legal Disputes and Pushback from Water Users: Some affected groundwater users challenged the curtailments, arguing that the state's modeling of stream depletion impacts was insufficient or inaccurate. However, the courts have largely upheld the State Engineer's authority to impose priority-based curtailments. Id.
- Continued Pressure for Additional Curtailments: Even after the 2020 actions, Colorado remains at risk of non-compliance with the compact. Further curtailments or additional water retirement measures may be required in the future to fully meet Kansas's legal demands. Kansas v. Nebraska & Colorado, 538 U.S. 720 (2003).

The Republican River Basin case provides several important takeaways for New Mexico and other arid regions managing groundwater in interconnected surface water systems:

- Interstate obligations can drive groundwater management decisions: Similar to New Mexico's obligations under the Rio Grande Compact, Colorado's experience shows how interstate legal agreements can necessitate curtailments, even when they impose significant economic costs.
- Curtailments based on priority doctrine require strong enforcement mechanisms: The case illustrates the importance of a clear legal and administrative process for curtailing junior groundwater users when necessary. The role of the State Engineer in enforcement is particularly critical.
- Mitigation efforts can ease, but not eliminate, the burden of curtailments: While voluntary retirement programs and augmentation projects can help alleviate some curtailment pressures, they often do not fully address compliance needs, meaning direct pumping restrictions remain necessary.

Colorado's experience in the Republican River Basin demonstrates the challenges of enforcing priority-based groundwater curtailments and the legal, economic, and hydrological complexities involved. The case highlights the necessity of integrating groundwater and surface water management, the difficulties of balancing water use with legal obligations, and the importance of mitigation tools to soften the economic impact of curtailments.

The Republican River Basin case serves as an interesting example for policymakers considering groundwater curtailments and offers valuable insights into managing hydrologically interconnected resources under a legal framework emphasizing priority water rights and interstate compact compliance.