Cannabis H_2O

WATER USE & SUSTAINABILITY IN CULTIVATION

Coauthored by:

RESOURCE INNOVATION INSTITUTE

Berkeley Cannabis Research Center

New Frontier data

Contents

letter from the **Publisher**

IN A PERFECT WORLD, cannabis cultivators could focus on terrior, the particular geographical and climactic influences which (as for wine vintners) influence a seasonal crop and vintage. In today's world, however, outside concerns intrude a bit more terribly: While environmental conditions have traditionally favored Western states of the United States for the outdoor cultivation of cannabis, the 21st-century's burden of changing climate conditions is increasingly leaving them vulnerable to some of the most acute drought conditions in the country. Arizona, California, Colorado, Nevada, New Mexico, and Oregon (which collectively account for 71% of the nation's total cannabis supply, both legal and illicit) are being keenly afflicted, according to the National Oceanic and Atmospheric Administration's Drought Monitor.

To better understand and anticipate the industry's realities and responsibilities, New Frontier Data and our report partners at the Resource Innovation Institute (RII) and the Berkeley Cannabis Research Center present ***Cannabis H2O: Water Use & Sustainability in Cultivation*** to foster a fundamental understanding of how, and how much, water is used for cannabis cultivation.

It has never been more incumbent upon industry to identify how it can improve resource efficiency. Indeed, the premium to be placed on systemic responsibility becomes ever more important as the nation's legalized cannabis markets expand. Including the latest five states which mandated programs in the November elections, New Frontier Data expects the overall legal U.S. cannabis industry to grow at a compound annual growth rate of 21% through 2025, to reach $41.5 billion. That figure represents more than 3x the $13.2 billion legal market of 2019. Our projections reveal that while legal production of cannabis represented nearly a quarter of the 2020 total U.S. market (including illicit sales), that share should increase to reach 35% of the market by 2025. Conversely, the nation's illicit market is expected to see sales decline from $66 billion in 2019 to $64 billion in 2025.

During that same period, researchers expect total water use in the legal cannabis market to increase by 86%. Though some critics and opponents have seized upon water use as a policy issue, the regulated, legalized cannabis industry In California generally uses significantly less water than do some of the Golden State's other major agricultural crops (e.g., cotton, tomatoes, wheat, and corn). That noted, it is a virtual given that the trend toward longer, more acute droughts will be sustained well into the future, which lends more urgency to the Water Working Group's efforts and messaging.

Cultivators are being advised to design, build, and operate their operations appropriately to address the changing adversity of climate conditions, including longer, hotter, and drier summer growing seasons. Cultivators will need to adapt to restrictions on water access. Facility operators will be tested by evolving building standards to increase energy efficiency, reduce waste, and preserve indoor and outdoor air quality via mechanisms like California's Title 24. There will be more carefully and expensively supplied municipal water, increased cooling demand for indoor and greenhouse growers to offset higher loads, and higher operational expenses for temperature control and water management systems.

As the legal cannabis industry matures, water-use efficiency will necessarily become more important, as it likewise will for other agricultural crops. Environmental and ecological pressures will mount, including for the reduction of input and energy costs, increased protection of the environment, addressing evolving regulatory standards, and ultimately being responsible stewards not only of industry but its ecology.

As with all our reports available through New Frontier Data's online intelligence portal Equio™, we trust that readers will benefit from this fact-based assessment, our unbiased insights, and the actionable intelligence provided to continue to succeed in the global legal cannabis arena.

New Frontier Data's mission is to elevate the discussion around the legal cannabis industry globally by providing unbiased, vetted information intended for educating stakeholders to make informed decisions. We provide individuals and organizations operating, researching, or investing amid the cannabis industry with unparalleled access to actionable industry intelligence and insights, helping each to leverage the power of knowledge to succeed in a fast-paced and dynamic market.

Please do enjoy our newest report as you shape your strategy and devise your action plan within the cannabis industry!

Giadha A. DeCarcer
Founder and CEO,
New Frontier Data

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executive Summary

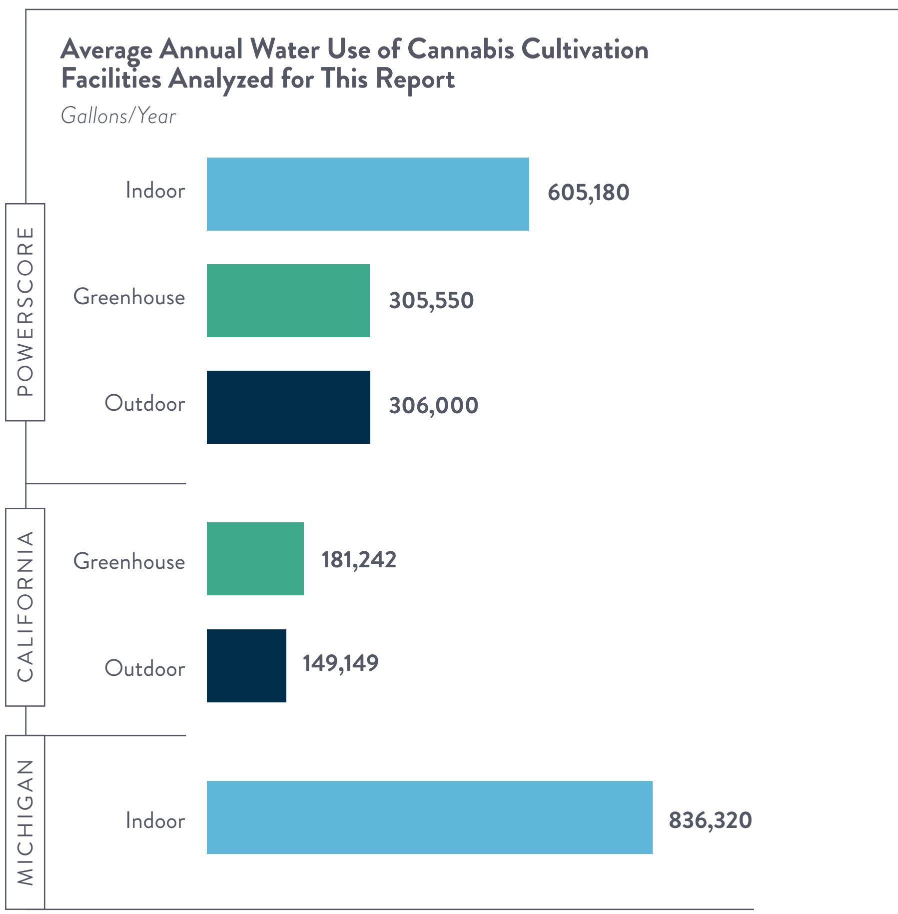
THE DRAMATIC EXPANSION of the legal cannabis industry in recent years has led to significant advances in the way that cannabis is grown. Surging consumer demand for legal products, coupled with increasing competition, has led growers to increasingly focus on improving operational efficiency to lower costs, optimize yields, and increase revenues. While substantial research has been conducted on energy use in cannabis cultivation, the use of water is far less well understood.

With the demand for legal cannabis forecast to double in the next five years, understanding how water is currently used — and how growers can reduce its use — is key for establishing industry practices to improve industry-wide efficiency at a critical stage in the industry's growth.

Using data collected by Resource Innovation Institute via its Cannabis PowerScore benchmarking platform and with researchers, utilities, and regulatory agencies in California and Michigan, this report explores ways that water is used by cannabis growers, establishes key benchmarks for water use across different types of facilities, identifies innovations that are driving greater water-use efficiency, and offers strategic recommendations for producers and regulators to advance water-use efficiency throughout the industry. Given the need for more data, it should be clearly understood that the numbers presented in this report are directional rather than representative of the broader regulated industry. Likewise, this report should not be conflated with a best practices guide.

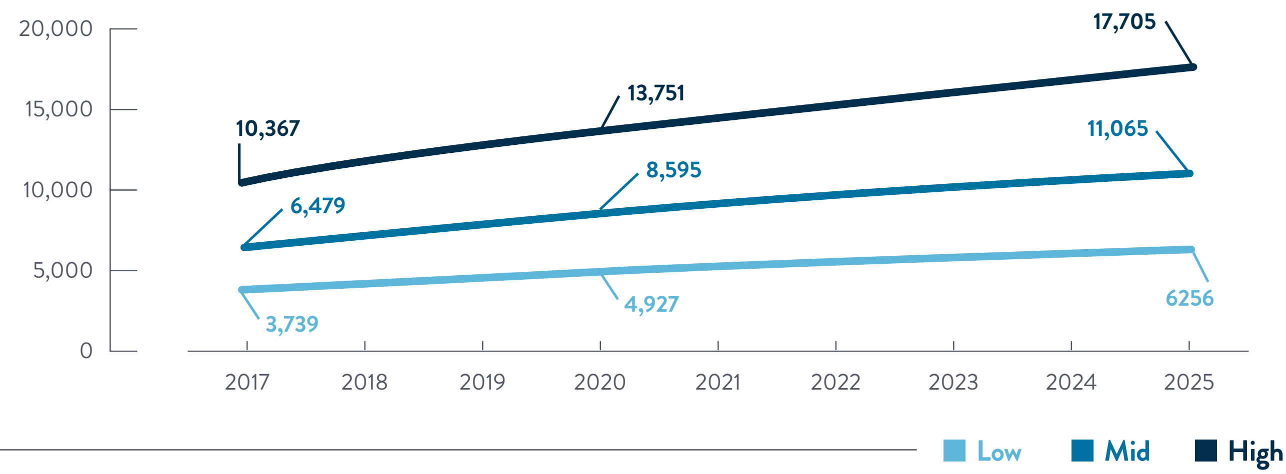
Cultivation Practices Are Keys to Water Use

- Water is used in a range of ways for cannabis cultivation. Irrigation is its primary use, but water is also used to dissolve nutrients, humidify and cool the cultivation environment, and manage pests or perform cleaning.



Total Industry Water Used in Cannabis Cultivation: Acre-Feet

Low/Mid/High Estimates



- Irrigation practices vary widely across facilities, ranging from hand-based irrigation with hoses, to piped irrigation systems with sensors measuring ambient conditions in real time, to application of micro-pulses of water to maintain moisture levels for optimal conditions. The transition from hand-watering to drip irrigation is one of the most basic but effective steps which growers can take to being reducing their water use.

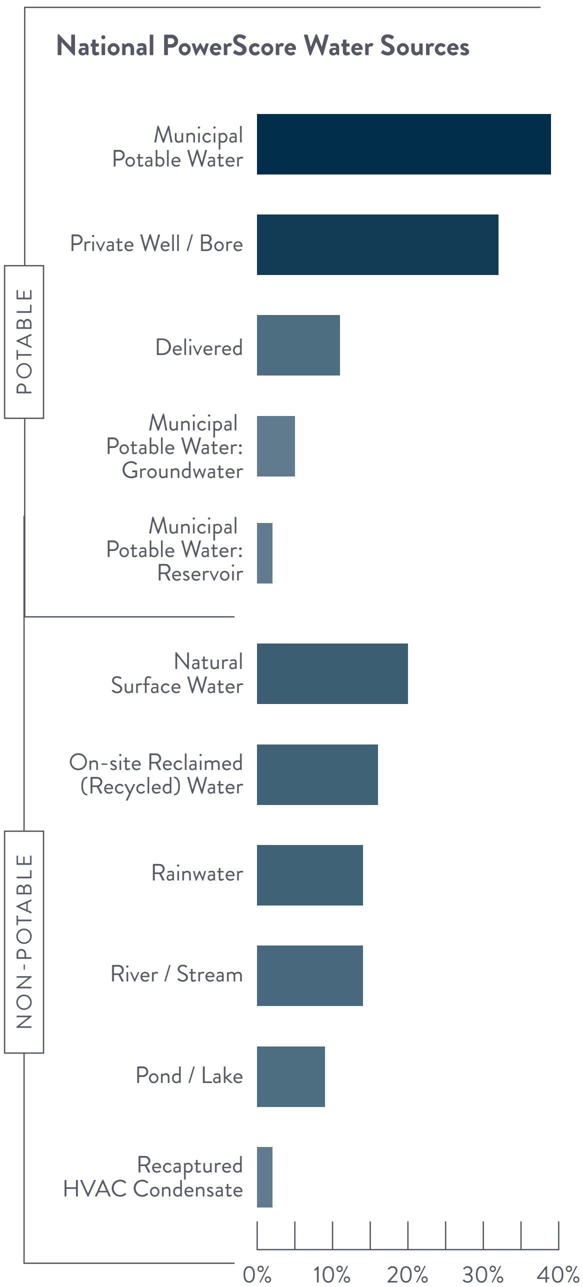
- The substrate – or medium in which the cannabis is grown – plays a critical role in irrigation, further complicating the ability to standardize disparate approaches for water use. Growers using soil can irrigate more heavily, but at only a few intervals per day, whereas an inert substrate like stonewool (or rock wool) has a high water holding capacity and can therefore be watered with lower volumes of water, up to 20 times per day.

- Water efficiency (i.e., gallons/square foot) is significantly influenced by the type of cultivation facility and the number of harvests. Indoor facilities (which have five or more harvests per year) use significantly more water per square foot per year, compared to outdoor facilities (which typically yield one harvest per year). On average, facilities use 121 gallons per square foot per year, with indoor facilities averaging 209 gallons, compared to outdoor facilities averaging 11 gallons per square foot per year. The number of annual harvests is obviously significant in the cyclicality of water use, with multi-harvest facilities requiring more steady water use throughout the year, whereas outdoor facilities are likelier to see their highest rates of use in late summer and early fall, as harvests approach.

Despite Surging Production and Market Revenues, Water Use in Cannabis is Nominal Relative to Other Major Agricultural Crops

- Compared to major agricultural crops, including cotton, grapes, and corn, the total water used to grow cannabis has a nominal impact on total water use in farming.

- While a wholesale pound of rice and table grapes sell for approximately $0.71, and $0.78 respectively, a wholesale pound of smokable cannabis bud can fetch $1,500 - $3,000 or more. This stark differential means the market value of the cannabis industry grows dramatically even with only incremental increases in production.



Reclamation and Reuse Present Underutilized Opportunities to Improve Water Efficiency

- Since more than 90% of water absorbed by plants is lost through evapotranspiration, a significant portion of water used in irrigation for indoor and greenhouse environments can be reclaimed as condensate collected in the facility's HVAC systems. However, few facilities are designed to collect, store, and treat condensate.

- Concerns about spreading pathogens or heavy metals through a grown environment has been a long-standing barrier to adoption of water reclamation practices. However, with effective water-recycling solutions becoming more commonplace, cost savings from reusing treated water are driving increased adoption of reclamation solutions.

Water Sources Used Vary Widely, with Each Presenting Different Options for Efficiency Gains

- Indoor growers are the most likely to use municipal water as their primary source, whereas greenhouse and outdoor growers are more apt to use onsite wells, natural surface water, or rainwater. Space constraints often limit onsite water storage in indoor facilities, whereas large-scale storage tanks are commonly used in greenhouses and outdoor facilities, especially in areas lacking stable water supplies.

- While growers in newer legal markets (especially those in the most recent Northeastern or Midwestern markets with reliable access to water) may feel less incentivized to prioritize water efficiency when building out their new facilities, established markets have shown that increased pricing competition puts enormous pressure over time on less-efficient operators. As such, it is critical that growers plan for downward price pressure as the market matures, and identify ways to reduce operational costs early. Instituting early, cost-saving best practices for water efficiency can enable growers in increasingly crowded markets to compete more effectively.

Benchmarking Water Use is Vital to Improving Industry-wide Outcomes, but Establishing Appropriate Metrics Is Critical

- Cannabis industry regulators should consider requiring licensed growers to report their water use (as some states have done) to encourage more data collection on the little-understood aspect of cultivation while enabling industry-wide data comparisons. Enabling growers to benchmark their water efficiency against their peers' will create incentives for less-efficient operators to improve their functional performance. Using tools like the Cannabis PowerScore resource benchmarking platform enables growers to compare their water efficiency against their peers' will create incentives for less-efficient operators to improve their functional performance.

- Establishing appropriate benchmarks will be key: The type and size of a facility must be considered to enable effective peer benchmarking. Similarly, while water use per plant has historically been used as an efficiency metric, wide variations in plant sizes and lengths of cultivation cycles effectively render a per-plant metric meaningless, thus it should not be used as a comparative performance indicator.

Climate Change Is Fueling Urgency to Reduce Water Use in Key Production Regions

- Key legal cannabis markets in Western states (e.g., Arizona, California, Colorado, Nevada, and Oregon) are currently experiencing historic drought conditions, with water shortages expected to become increasingly pronounced as effects of climate change become more acute. Facing a future of both increased water scarcity and higher water costs is stirring new urgency to increase production efficiency in the country's most productive cannabis cultivation markets.

- Governments and industry regulators can play important roles by incentivizing growers to adopt water-efficiency solutions as parts of broader government efforts to mitigate impacts from climate change on the agricultural economy.

With the legal cannabis market in the U.S. positioned for catalytic growth over the next five years, and with many more countries enacting laws legalizing cannabis use, efficiency practices adopted now will play defining roles in reducing the industry's total water use during this critical stage of its growth.

About
New Frontier Data

NEW FRONTIER DATA is an independent, technology-driven analytics company specializing in the global cannabis industry. It offers vetted data, actionable business intelligence and risk management solutions for investors, operators, researchers, and policy makers. New Frontier Data's reports and data have been cited in more than 85 countries worldwide to inform industry leaders. Founded in 2014, New Frontier Data is headquartered in Washington, D.C., with additional offices in Denver, CO, and London, U.K.

New Frontier Data does not take a position on the merits of cannabis legalization. Rather, its mission and mandate are to inform cannabis-related policy and business decisions through rigorous, issue-neutral, and comprehensive analysis of the legal cannabis industry worldwide.

For more information about New Frontier Data, please visit: NewFrontierData.com.

Mission

New Frontier Data's mission is to elevate the discussion around the legal cannabis industry worldwide by providing unbiased and vetted information intended to educate stakeholders to make informed decisions.

Core Values

- Honesty
- Respect
- Understanding

Vision

Be the Global Big Data & Intelligence Authority for the Cannabis Industry.

Commitment to Our Clients

The trusted one-stop shop for actionable cannabis intelligence, New Frontier Data provides individuals and organizations operating, researching, or investing in the cannabis industry with unparalleled access to actionable industry intelligence and insight, helping them leverage the power of big data to succeed in a fast-paced and dynamic market.

We are committed to the highest standards and most rigorous protocols in data collection, analysis, and reporting, protecting all IP and sources, as we continue to improve transparency into the global cannabis industry.

Report Contributors

PUBLISHER

Giadha A. DeCarcer, Founder & Chief Executive Officer, *New Frontier Data*

EDITOR

John Kagia, Chief Knowledge Officer, *New Frontier Data*

AUTHORS

Gretchen Schimelpfenig, PE, Technical Director, *Resource Innovation Institute*

Derek Smith, Executive Director, *Resource Innovation Institute*

Chris Dillis, Post-Doctoral Fellow, *Cannabis Research Center, University of California, Berkeley*

Van Butsic, Dept. of Environmental Science, Policy & Management, *University of California, Berkeley*

ADDITIONAL ANALYSIS

Kacey Morrisey, Director of Industry Analytics, *New Frontier Data*

Noah Tomares, Industry Analyst, *New Frontier Data*

COPY EDITOR

J.J. McCoy, Senior Managing Editor, *New Frontier Data*

PROJECT MANAGEMENT

Hovanes Tonoyan, Project Manager, *New Frontier Data*

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RII TECHNICAL ADVISORY COUNCIL WATER WORKING GROUP MEMBERS

Andrew Alfred, LivWell Enlightened Health
Barb Anderson, Washington Dept. of Ecology
Chris Dillis, Berkeley Cannabis Research Center
Rob Eddy, CEA Consultancy LLC
Matthew Gaboury, House of Cultivar
Hollie Hall, Compliant Farms Certified, LLC
Michael Heaven, Argus Controls
John Kagia, New Frontier Data
Kyle Lisabeth, Silver Bullet Water Treatment
Bob McDonald, Carpinteria Valley Water District
Chuck Nora, Desert Aire
Austa Parker, Denver Water
Sara Schoenhals, HydroLogic
Elizabeth Shilling, Ceres Greenhouses
Madison Walker, Grodan
Jan Westra, Priva
Beau Whitney, Whitney Economics
Cale Winters, Rhythm CSS
Al Zylstra, Dramm Corporation

PEER REVIEWERS

Van Butsic, Berkeley Cannabis Research Center
Shaye Donald, Hawthorne Gardening Company
Jean-Pierre Fortin, Hawthorne Gardening Company
Ted Granthan, Berkeley Cannabis Research Center
Brad Hull, Integrated Bioengineering
Jesse Porter, InSpire Transpiration Solutions
Michael Robbie, Conviron
Andy Souza, TEP Engineering
Marielle Taft, Grodan
Patrick Walters, Lansing Board of Water & Light

About
Our Partners

Resource Innovation Institute

Resource Innovation Institute (RII) is an objective, data-driven non-profit organization who establishes industry standards, facilitates best practices and advocates for effective policies and incentives that accelerate conservation. With its Cannabis Power-Score benchmarking platform, RII helps producers confidentially assess the efficiency and productivity of their cultivation facilities using industry-standard Key Performance Indicators (KPIs) on energy, emissions, water and waste. RII's Technical Advisory Council brings together multidisciplinary stakeholders and subject matter experts to define best practices through comprehensive peer review. As an aggregator of knowledge, RII trains the market and informs governments and utilities about baselines and standards for resilient, high-performance production.

Cannabis Research Center

The Cannabis Research Center (CRC) is a research group based at the University of California, Berkeley. Our goal is to promote interdisciplinary scholarship on the social and environmental dimensions of cannabis production. Through scientific research and engagement with community, government, and academic entities, we advance understanding of cannabis agriculture in socioecological systems at local, national, and global scales. We seek to inform public dialogue and contribute to the development of prosperous communities and healthy environments.

Introduction

Water Used for Cannabis Cultivation

Irrigation Practices Vary Widely Across the Industry, with Many Opportunities to Improve Efficiency

Compared to other commercial horticultural sectors where decades of agricultural research and innovation have normalized cultivation practices, in cannabis (where the illicit market still accounts for the majority of crop grown) growers use a wide range of irrigation techniques ranging from high-volume/low-frequency events (where the crops are heavily watered by hand once or twice a day), to low-volume/high-frequency models where the crops receive small bursts of water 20 or more times per day, delivered via state-of-the-art, sensor-based irrigation systems.

Federal prohibition has further hampered efforts to understand resource use and efficiency opportunities, as research institutions which receive federal funding have been prohibited from conducting research on cannabis that would inform cultivation best practices. While there has been cultivation research done in other countries (notably Israel and Canada), the lessons from those studies are not always readily applicable to local conditions in the U.S.

Expansion of the legal market is leading to greater transparency into cannabis cultivation practices, and greater prioritization of efficiency and operational cost containment. As a result, growers have begun to transition from larger substrate volumes and less efficient watering techniques, to smaller pot sizes and greater integration of more precise irrigation techniques (e.g., high-frequency/low volume irrigation). No matter how water is applied, grower methods can be optimized, and opportunities to increase efficiency of water use across the industry are considerable.

Benchmarking water use, defining its best practices, and educating growers on the economic and environmental benefits of reducing their water use will be keys to ensuring that water efficiency is a priority for integration into the next stage of the legal cannabis market's growth.

Limited Analysis of Water Efficiency, and Fears that Operational Disruptions Have Slowed Progress Toward Optimizing Water Use

As the economics of cannabis have shifted with increased competition and downward price pressure, cost containment has been a critical issue for growers. Since operational efficiency was not considered a priority in the illicit market, many opportunities exist across cultivation environments to increase resource efficiency and lower costs. Some examples include: 1) reducing energy demand and consumption by using LED lighting systems; 2) switching from sole-source lighting treatments for indoor cultivation to greenhouse or mixed-light environments which use natural light; 3) leveraging automation to reduce labor costs and optimize operational performance by employing automatic trimmers or sensor based technologies to monitor and manage climatic conditions in the grow environment; or 4) analyzing use of cultivation inputs from nutrients to substrate to minimize waste and negotiate better rates from suppliers to lower expenses.

While growers may understand the positive impact of reducing water use on the environment, there has been far less research done into the role that efficient water use can play in improving an operation's bottom line. Consequently, growers often incorrectly overestimate the cost of deploying water management solutions while underestimating the impact that those strategies have on lowering business costs.

Getting growers to view water efficiency not just as an environmental benefit but as a business opportunity will be a key step in accelerating adoption of water optimization solutions for cannabis cultivation.

Legalization Is Reducing Water-Related Environmental Harm Caused By Illicit Grows on Public Land

The environmental impact of illegal (i.e., trespass) cultivation on public lands is among the less prominent but immensely consequential outcomes of unregulated cannabis production. Throughout the western United States in particular, cannabis cultivation in national forests and other public lands has had devastating effects on the ecology and watersheds where the cannabis has been grown. Trespass growers may dam streams or divert water flow for their plants, and unmanaged runoff from their operations can result in the introduction of fertilizers, pesticides, rodenticides, and other contaminants to the watershed, causing significant environmental damage downstream.

Yet, two recently published peer-reviewed manuscripts[2] provide encouraging news. Both papers show evidence how states that legalize cannabis see a decrease in trespass cannabis grows on federal lands. By extension, the decrease in trespass grows likely also leads to decreased environmental harms.

The emerging research suggests that legalizing cannabis market can lead to some environmental wins. If combined, regulatory compliance in the legal market, coupled with the economic advantage of reducing operational costs, leads to more careful management of water resources and heightened focus on minimizing water use in the legal market. In turn, an economically and environmentally successful legal market reduces the environmental harms caused by unregulated growers by undermining their profitability. All told, a water-efficient legal market has the potential to help reduce trespass growing, and may do so more effectively than could be achieved solely through increased prohibition and enforcement.

Beyond water use, legalization is stimulating some increased focus on resource use and efficiency management across the cannabis ecosystem. As noted in the 2018 Energy Report and in RII's ongoing energy and resource management research, the legal industry is driving significant gains for energy efficiency in cultivation, both as best practices become more normalized and performance-improving technologies (e.g., LED lighting systems and climate-monitoring solutions) become more widely adopted. These trends are expected to continue as the legal market expands and matures.

2. *Prestemon, J.P., Koch, F.H., Donovan, G.H. & Lihou, M.T. (2019). Cannabis legalization by states reduces illegal growing on US national forests. Ecol. Econ., 164, 106366.*

Klassen, M. & Anthony, B.P. (2019). The effects of recreational cannabis legalization on forest management and conservation efforts in U.S. national forests in the Pacific Northwest. Ecol. Econ., 162, 39–48.

Water Use in Cannabis Cultivation

WATER SOURCES

Cannabis growers use a variety of sources for both potable and non-potable water, depending on water availability in their regions and the cultivation practices used by operators (please consult the glossary for more information about each water type).

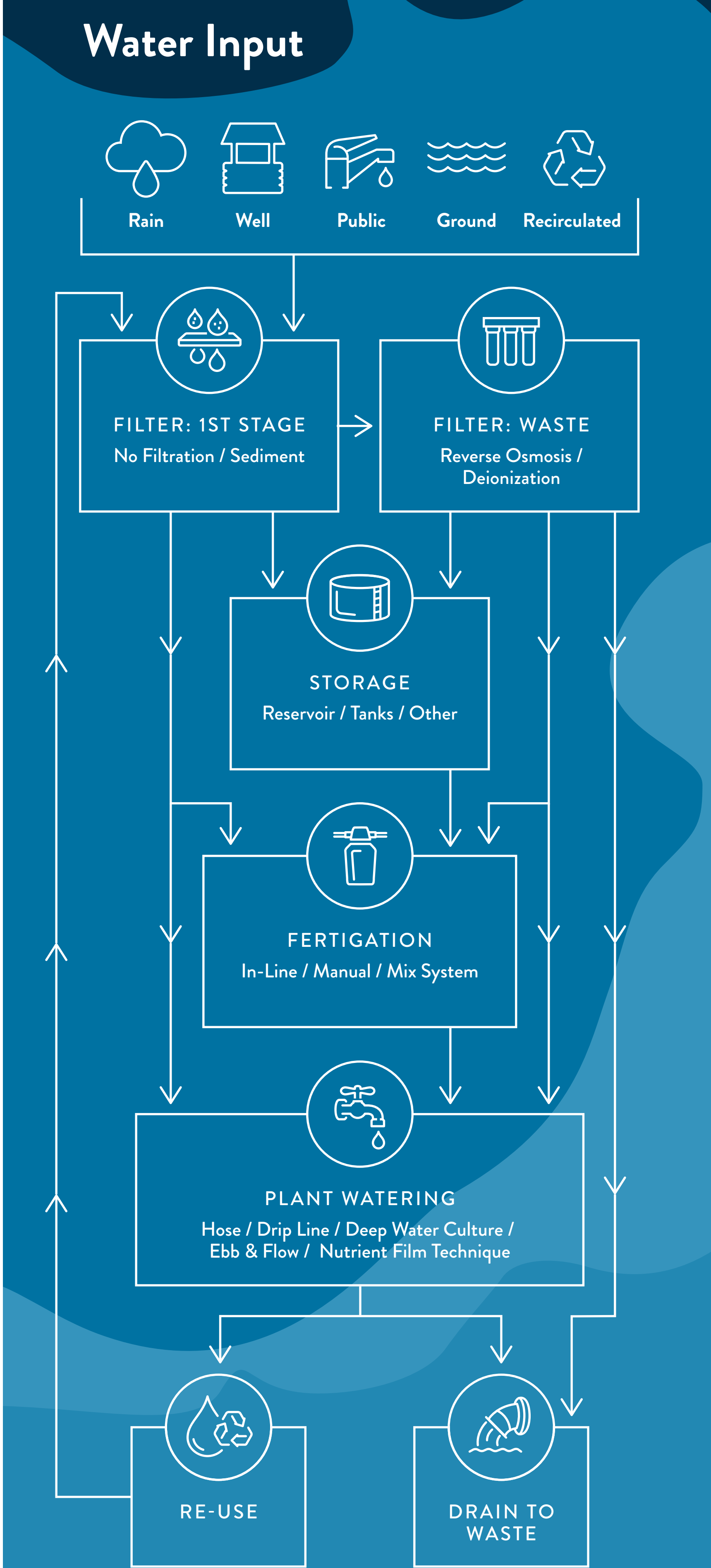
- **Potable**
  - Municipal Potable Water
  - Delivered Water
  - Private Well / Bore
- **Non-potable sources**
  - On-site Reclaimed (Recycled) Water
  - HVAC Condensate
  - Natural sources
    - Rain
    - Surface Water

WATER USE IN CANNABIS CULTIVATION FACILITIES

Generally, cannabis cultivation facilities use water in eight ways:

1) Irrigation: Ensuring that plants remain appropriately hydrated during their life cycle;

2) Storage: While some facilities irrigate directly from a water source, many facilities have temporary water storage tanks for filtration and fertigation . Operators of facilities with limited or



unreliable water supplies will often have more substantial long-term storage capacity to ensure keeping water on site for future irrigation;water storage is a key aspect for cultivation;

3) **Applying nutrients or other dissolved substances to the plants:** Many growers mix root zone inputs into their irrigation water, adjusting formulations based on plant needs at each stage of growth;

4) **Humidification:** Maintaining the optimal ambient moisture level in the grow environment (especially in indoor cultivation facilities);

5) **Cooling:** Drawing out excess heat from the grow space using HVAC and dehumidification equipment;

6) **Cleaning:** Maintenance of the cultivation equipment;

7) **Pest Control:** Water can be an effective way to keep pests off plants without applying chemical treatments; and

8) **Non-Cultivation:** Water used for 'domestic' activities like handwashing, toilets, and kitchen areas for employees.

Of these applications, irrigation is the most water-intensive application.

However, irrigation also presents the greatest opportunity for water reclamation. Since plants use as much as 99%[3] of the water they absorb to keep the leaves cool and move nutrients through the plant via evapotranspiration, the vast majority of water applied in indoor and greenhouse facilities can often be reclaimed and reused. There are two types of recapture and reuse: recapture of irrigation runoff water and recapture of HVAC condensate (water in the air from evapotranspiration).

HVAC water makes up the majority of reclaimed water. The amount of nutrient runoff water that can be recaptured depends greatly on the grow strategy (deep water culture will produce more runoff than soil). Recaptured runoff water must be treated differently than the HVAC water before reuse. Depending on the water treatment system, we sometimes find that the energy requirements for treating this water is not worth the amount of water reclaimed.

3. Sterling, T, Transpiration – *Water Movement through Plants', New Mexico State University, 2004*

A NOTE ABOUT WATER USE FOR CLIMATE CONTROL IN GREENHOUSES

Many greenhouses use evaporative cooling pads to control temperatures in warmer seasons. As a result, water use in greenhouses can triple during the summer, not just due to higher irrigation requirements, but also because when the evaporative pads are running (and pumps trickle water over them), some water runs off, typically into drains, to keep salts from accumulating in the pump reservoirs. With 24 greenhouse rooms each running off 0.5 gpm water for 8 hours on a 90-degree day, usage for evaporative cooling can exceed 5000 gallons/day.

As a result, evaporative cooling can significantly drive up water requirements in greenhouses located in hot, arid areas.

Solutions to Increase Water Efficiency in Cannabis Cultivation

Growers Have an Array of Options to Reduce Water Use

Growers use different techniques to apply water to their crops, including using a hose to water individual plants, using drip irrigation solutions, and using hydroponics, where the plants' roots are routinely flushed with a nutrient solution (examples include deep water culture, nutrient film technique, and aquaponics).

There is a wide array of ways in which technology is helping reduce water use:

DRIP IRRIGATION

Perhaps the most widely used water efficiency solution, drip irrigation systems allow growers to direct water to each individual plant without having to irrigate the entire cultivation area. Compared to using a hose to irrigate the plants, or to a flood-and-drain technique which is highly water-intensive, the precise targeting of drip irrigation[4 5] can reduce water consumption by 30% to 70%, and improve water productivity by 20% to 90% (potentially more if the hose is not turned off as it is being moved between plants, a practice which can waste as much as 50% of applied water if the plants are not densely packed together).

4. Zafari, J ,Mohammadi, N, A Review on Drip Fertigation on Field Crops, International Journal of Engineering Research & Technology, 2/12/2019

5. O'Connor, N, Mehta, K. Modes of Greenhouse Water Savings, Procedia Engineering, Vol. 159, 2016

Research by Dr. Neil Mattson of Cornell University, for one, has shown that the efficiency of drip irrigation systems can be further enhanced through the use of substrate and ambient environment sensors which monitor each the moisture continent, temperature, humidity, and electrical conductivity of the cultivation environment in real time, and can automatically start and stop irrigation whenever conditions reach preprogrammed parameters.

SENSOR-BASED MICRO-PULSE IRRIGATION

A more advanced variant of drip irrigation systems is the use of sensor-based systems that deliver steady micropulses of water to each plant. While the technologies are not widely available at scale, researchers have found that the use of microbursts of water or nutrient solution are far more water-efficient than even drip irrigation methods which tend to saturate the grow medium, resulting in higher levels of runoff.

One agricultural researcher reported that a self-built, microsensor-based system used up to 20 times less water than hose-based irrigation, with equal to better crop yields. Additional benefits of such a system include:

- **Fewer pests,** such as fungus gnats and shore flies, which are attracted to the moisture in the grow medium and are often seen in heavily watered plants; and
- **The ability to simulate drought conditions** through the precise calibration of the amount of water reaching the plant: For some cannabis plants, drought conditions have been shown to stimulate production of some cannabinoids, which are becoming increasingly valuable in legal markets.

As the cannabis industry matures, the deep integration of sensor-based technologies will become more commonplace as growers seek to optimize their use of resources and maximize the performance of their crops. Already, many producers are optimizing the timing of fertigation cycles based on measurements of what is happening to the plant, by weighing plants and using measurements to determine how much of the feeding and watering cycle has been completed. Some producers are measuring the moisture content in the substrate, and using the change in moisture to determine when the plants should be fed/watered. Other growers measure the moisture content of the leaves, and use the information to decide on feeding and watering cycles as opposed to simply basing those cycles on time.

LEACHATE CAPTURE AND RECIRCULATION

Depending on the watering techniques used, 25% or more of the water applied runs off into the drain; when applying water using a hose in indoor facilities, often half of the applied water does not reach the pot. Reclaiming and reusing irrigation runoff is widely done in other horticultural sectors: The tomato sector in particular, where tight margins have driven major technological advancements to maximize water efficiency, deploys effective solutions readily replicated for cannabis. Advancements in water reclamation and discharge reduction have also largely been driven by increasingly stringent regulatory action on behalf of large greenhouse-producing countries and regions. For example, the Netherlands has a goal of zero discharge by 2027, and similarly strict regulations in Ontario are helping drive innovation and increase water-use efficiency.

However, two operational concerns have slowed adoption of reclamation and reuse for cannabis cultivation:

- **Concerns about the effort required to process reclaimed water for reuse.** Runoff from irrigation has a different nutrient profile than the solution applied to the plant, which is based on how much of each nutrient in the water the plants absorbed. Consequently, growers must carefully and routinely test runoff to determine how the nutrient profile has changed, then meticulously rebalance the solution to restore it to optimal levels. In most cases, growers must do significantly more than simply test runoff to accurately rebalance drain-recaptured solution to the correct elemental parts-per-million (ppm) contributions. The runoff profile is different due to the fact that plants remove ions from aqueous solutions at demonstrably different rates[6], so cumulative nutrient imbalances are prone to occur. Concern about errors made during the process of testing and reformulation has led many growers to conclude that it is both easier and safer to use new water.

An empirically sound strategy involves combining runoff analysis, pore water extraction analysis, and leaf tissue analysis to correctly reinject elements or fertilizers parts at appropriate doses. Such testing is almost invariably done by third-party labs rather than in house, due to the technical nature of analysis and the necessarily high frequency of instrumentation calibration.

> Depending on watering techniques, 25% or more of applied water drains as runoff.

6. *Bugbee, B., Nutrient Management in Recirculating Hydroponic Culture, Acta Horticulturae, 2, 2004*

However, rebalancing can be achieved successfully during the process of introducing additional new water to offset nutrient loss. Sensors can supplement water-quality testing to make the process more efficient.

An alternative is to use filtration and scrub out the nutrients with processes like reverse osmosis (RO), which reduces the reuse efficiency (though 50% reuse is better than 0%).

- **The risk of distributing pathogens or other contaminants into the grow environment.** Another key concern is the risk of distributing waterborne malignant or opportunistic plant and root-zone pathogens, such as Pythium and Fusarium (i.e., root rot from pathogens that affect roots and stems), into the full operation through contaminated reclaimed water. If the reused water is not processed correctly, isolated issues with a limited number of plants can quickly spread throughout the operation, putting the entire crop at risk. For many growers, the downside risk of losing an entire crop outweighs the cost savings and efficiency gains to reclamation and reuse.

While those concerns are understandable given the high value of each cannabis harvest, they belie the reality that many well established solutions already exist to increase water efficiency in cultivation, as widely used in other horticultural markets.

RECLAMATION OF HVAC CONDENSATE

In indoor and greenhouse facilities, HVAC and dehumidification systems can capture significant proportions of the water lost through evapotranspiration. Often, reclaimed water is discarded, but given the volume of water being extracted it presents a significant opportunity for reclamation and reuse, either for irrigation or other applications throughout the cultivation facility.

There are some considerations when reclaiming condensate from HVAC and dehumidification systems:

- WATER STORAGE
  For space constrained operations, installing the large-scale water tanks needed to store all the condensate can be an issue, especially when being added to an already existing facility. However, for newly built facilities or those with room to expand, adding water storage capacity can be relatively easy and inexpensive.
- WATER PURIFICATION
  Some HVAC systems apply disinfectants or other chemicals to prevent algae and other microbiological growth in the reclaimed water. Growers must therefore plan to process chemicals that may negatively impact plant growth from the water before it is reused.
- COPPER OR ZINC CONTAMINATION
  HVAC systems that use copper piping can often accumulate significant levels of copper in the condensate (see Figure 4 for typical contaminant levels in condensate samples). Zinc can build up in systems of facilities using galvanized metal plumbing. Shifting to PVC or other leach-resistant piping can reduce the risk of heavy metal contamination when the condensate is applied to the crops. However, regular testing of condensate water for microbiological and heavy metal contamination is the best way to ensure that the condensate does not introduce adulterants to the growing environment.

FIGURE 1: Chemical Contaminants in HVAC Condensate

	Chemical Contaminant	Aluminum	Calcium	Copper	Iron	Lead	Magnesium	Nickel	Potassium	Sodium	Zinc
Condensate Samples	Practical Quantitation Limit (PQL)	0.050	1.00	0.010	0.050	0.010	0.050	0.010	1.0	1.00	0.010
Condensate Samples	Number of Samples in Which Contaminant Detected	3	0	13	2	0	1	1	0	1	15
Condensate Samples	Values/Range of Detected Contaminant	0.053 0.078 0.547	–	0.016 - 1.34	0.130 0.956	–	0.059	0.171	–	11.3	0.018 - 0.267
Condensate Samples	Average of Detected Contaminant	0.226	–	0.23	0.543	–	0.059	0.171	–	11.3	0.18
	Drinking Water Primary Maximum Contamination Level (PMCL)	–	–	1.3	–	0.015	–	–	–	–	–
	Drinking Water Secondary Maximum Contamination Level (SMCL)	0.2	–	1.0	0.3	–	–	–	–	–	5
	SAWS Drinking Water Quality	<0.02	56.2 - 99.0	<0.002 - 0.379	<0.01 - 0.0191	<0.001 - 0.0163	8.99 - 18.2	0.0011 - 0.0062	1.10 - 6.53	8.08 - 23.4	<0.005 - 0.0328

REVERSE OSMOSIS (RO) FOR WATER PURIFICATION & LEACHATE RECLAMATION

Water is a common source of heavy metal contamination, particularly when sourced from rivers containing industrial pollutants. Plants deal with heavy metals by evolving either to limit root absorption, or by allowing absorption and sequestering the heavy metals where they can do less physiological harm (e.g., in the cell vacuoles or specialized proteins). Unfortunately, cannabis is one among such bioaccumulators.

RO is widely used in cannabis facilities to purify water from municipal, groundwater, or reclaimed sources. RO allows growers to apply uncontaminated water to their crops due to the effectiveness of the process in removing pollutants and adulterants from the water. It is especially important in places where municipal and groundwater has high levels of sodium, such as coastal areas in the western U.S. states. Since the cultivation techniques developed in the early markets of California, Oregon, and Washington have been adopted by growers nationally, and water-quality issues impact U.S. communities, the use of RO has expanded nationwide.

While RO has gained traction in the industry, it is worth noting that cannabis is the only major U.S. horticultural sector that uses RO for water treatment. RO water is especially helpful in cannabis because it is one of the only means to remove sodium and heavy metals from the plant, hence its widespread use in converting seawater to potable water. Given the stringent testing for heavy metals in cannabis, removal of such adulterants in water is critical for growers to ensure that their products are regulations-compliant. Growers thus err on the side of caution with the costly but effective method for treating water.

There are several reasons why RO is not more widely used in commercial agriculture:

- **RO generates a lot of waste.** While the most efficient systems can yield 1 gallon of brine (i.e., waste water) for every 10 gallons of purified water produced, less efficient systems produce 1 or 2 gallons of clean water per each gallon of brine.
- **RO energy intensive:** Running RO equipment uses a lot of electricity, offsetting efforts to reduce energy use in the cannabis operation.
- **RO water is significantly more prone to pH fluctuation:** Due to its low buffering capacity and lack of bicarbonates, maintaining RO water's optimal pH levels requires careful management to ensure optimal nutrient absorption. RO water's low TDS content of permeate allows it to absorb gaseous contaminants (e.g.,volatile organics and CO2), which tends to lower pH levels

One way to potentially reduce the high cost of using RO water as the sole source of irrigation water is to use a mix of it with municipal or ground water. However, with strict cannabis testing requirements for heavy metals and other adulterants unlikely to change, RO will likely remain commonplace in cannabis in the medium term, even as the sector is poised for innovation both to reduce cost and increase efficiency of water purification processes.

Growing Systems and Substrate Options

Choices for substrate are influenced by cultivation approaches and system choices.

CULTIVATION APPROACH AFFECTS PLANT SIZE

- **Indoor**
  - Sea of green
  - Larger plants
- **Greenhouse**
  - Medium plants (3- to 5-gallon pots)
  - Large plants (>10-gallon pots)
- **Outdoor**
  - Field/in-ground
  - Container-grown (100- to 1,000-gallon containers)
    - Cannabis plants grown fully outdoors without any structural covering are often grown to prioritize the size of individual plants. Plants may be grown directly in existing topsoil, or more often in planters or bags of imported substrate.
    - Outdoor plants often attain heights of 8 feet or more, with a diameter of over 10 feet. In comparison with smaller plants grown indoors or in greenhouses, a relatively higher proportion of biomass is dedicated to their vegetative (i.e., nonflowering) growth for structural support.

WATER MANAGEMENT APPROACH AFFECTS SUBSTRATE & LEACH PERCENTAGE

- **Hydroponic**
  - Deep water
  - Aeroponics
  - Recirculating (no leach) approaches such as deep water culture, aeroponics, top feed drip reclaim, or ebb-and-flow
- **Rock wool**
  - Drain to waste
  - Recirculating (i.e., with no leach)
- **Coir**
  - Minimal leach
  - Leach (10% to 25 %)
- **Peat**
  - No or minimal leach
  - Leach (10% to 15 % range)

Approaches to Water Disinfection

An Overview

There are typically at least two steps required for disinfecting cultivation water supplies:

1 **Pre-Treatment/Pre-filtration:** Removing organic and organic debris, including plant material, sediment, and algae.

2 **Sanitation:** A purification process which removes potentially harmful contaminants including microbiological organisms, heavy metals, and residual chemicals.

Treatment solutions can include physical, chemical, and biological systems, as summarized below. The systems are often used in combination to achieve optimal results.

PHYSICAL

Eliminate contaminants either by passing them through the treatment system, or by killing organisms in the water without removing them. Treatment methods generally do not have a residual effect on the irrigation system itself, and generally have no phytotoxic effects. Physical treatment generally does not prevent biofilm buildup or prevent clogging.

- Filtration – from sand separators to reverse osmosis
- Rapid media filtration (rapid sand, greensand, activated carbon)
- Ultraviolet irradiation
- Heat treatment (pasteurization)

CHEMICAL

Chemical treatment systems function by damaging cell membranes and/or internal cell organs, causing organism death. Chemical treatment can also prevent biofilm buildup in an irrigation system.

- Oxidizing agents
  - Chlorine & Bromine – oxidation to destroy organisms such as algae, fungi, and bacteria
    - *Bromine*
    - *Calcium hypochlorite (solid); 60-70% available Cl*
    - *Chlorine dioxide*
    - *Chlorine gas*
    - *Electro-Chemical Activation (ECA)*
    - *Sodium hypochlorite (liquid; bleach)*
  - Hydrogen Peroxide, Peroxyacetic acid
  - Ozone
- Combined Physical and/or Chemical: Advanced Oxidation
- Copper and Silver
  - Copper ionization
  - Copper salts
  - Copper / spin-out fabric liner
  - Silver

BIOLOGICAL

Biological treatment systems generally combine a number of treatment processes: physical separation, competition by other organisms, or creating an unfavorable environment for pathogens. These systems can often provide nutrient removal, and manage water that cannot be recirculated.

- Slow media filters and fluidized beds
- Constructed wetlands
- Wood chip denitrification bioreactors
- Hybrid treatment systems
- Bioswales
- Vegetated filter strips
- Land application

NOTE: Biological systems are often implemented outdoors, and are responsive to temperature. Design consideration should be given to temperature management in regions which experience extreme fluctuations during the year.

Source: Adapted from Water Treatment Guide for Greenhouses & Nurseries, West, J., Huber, A., Carlow, C., April 9, 2018

Impact of Substrate on Irrigation Frequency

Below is an overview of the most commonly used substrates used for indoor and greenhouse cultivation, in order based on prevalence of use in the legal market.

Note that the ratio of selected substrate volume to plant biomass will dictate the volume and frequency of irrigation events alongside physical properties and water-behavior characteristics. Growers may use a large volume of peat substrate that only demands low-frequency irrigation but larger volumes of water per event to reach uniform saturation. Others may have a small volume of substrate that necessitates higher-frequency irrigation but in lower volumes due to the overall lower water-holding capacity.

COCONUT COIR

Higher-frequency, lower-volume irrigation strategy: Coir irrigation can range between 1 and 12 water application events/day (depending on the size of the pot).

Coconut coir substrate has for over a decade been a very popular growing substrate in the cannabis industry. Growers like to use it because the physical and chemical properties of coir make it ideal for a range of different irrigation practices, container sizes, environmental conditions, and nutritional strategies.

Proper composition of coir (e.g., pith, fiber, and chunks) provides excellent water retention, aeration, and drainage under both frequent and less frequent irrigation practices across a variety of container sizes. The chemical properties of properly composted, washed, and buffered coir also provide an optimal pH range, while having low electrical conductivity, sodium and potassium content.

Coir is often used on its own, or mixed with perlite, commonly using a 70% coir/30% perlite ratio. It is compostable and can be sustainably produced, but coir requires significant volumes of water during the manufacturing process to remove unwanted ions that adsorb to the cation exchange sites. If sodium and other chemicals are not washed from the coir they can negatively impact growth performance.

ROCK WOOL (STONE WOOL)

Higher-frequency, lower-volume irrigation strategy (more extreme than coco coir): Grodan (the leading producer of rock wool for horticultural use) recommends up to 20 irrigation events a day, depending on the needs of the crop.

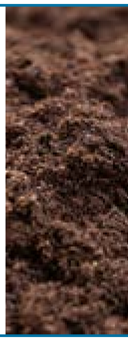
Rock wool (i.e., stonewool or mineral wool) is a fibrous material made from molten rock, spun into fibers and then formed into plugs, blocks, and slabs of varying sizes and shapes. It is an inert substrate, meaning that it does not bind any applied water and nutrition, and therefore has no influence on the availability of the nutrient solution delivered by the grower. The sterile nature of production under extreme temperatures keeps the substrate clean and free of pests and pathogens. That means that it has to be constantly irrigated with nutrient solution in order to provide nutrients to the crop.

Rock wool has a high water-holding capacity relative to its volume when compared with other substrates, due to its high volume of air. It can be irrigated with varying volumes and frequencies of water in relation to the volume of the substrate, and based on the differing needs of the plants during the cropping cycle. With uniform fibers and structure, water and nutrient contents can be controlled with minimal leachate.

Rock wool is sometimes referred to as a “sports car” of the substrate world: It can deliver very high plant performance, but if not carefully managed it is easy to‘“crash” as plant development happens extremely quickly and can require closer monitoring to ensure balanced production. Because of its low water retention, if rock wool irrigation is off or goes down, plants can more easily experience drought stress or even permanent wilting damage/death. There is a learning curve to using rock wool, especially in the cannabis industry where growers are used to irrigating once or twice a day rather than on the average of 8 to 14 irrigation events required for rock wool.

Because rock wool is inert and ions are not bound or exchanged on substrate particle surfaces, it requires a relatively high leachate percentage to keep its pore water solution elementally balanced and avoid cumulative nutrient imbalances in the plant tissue.

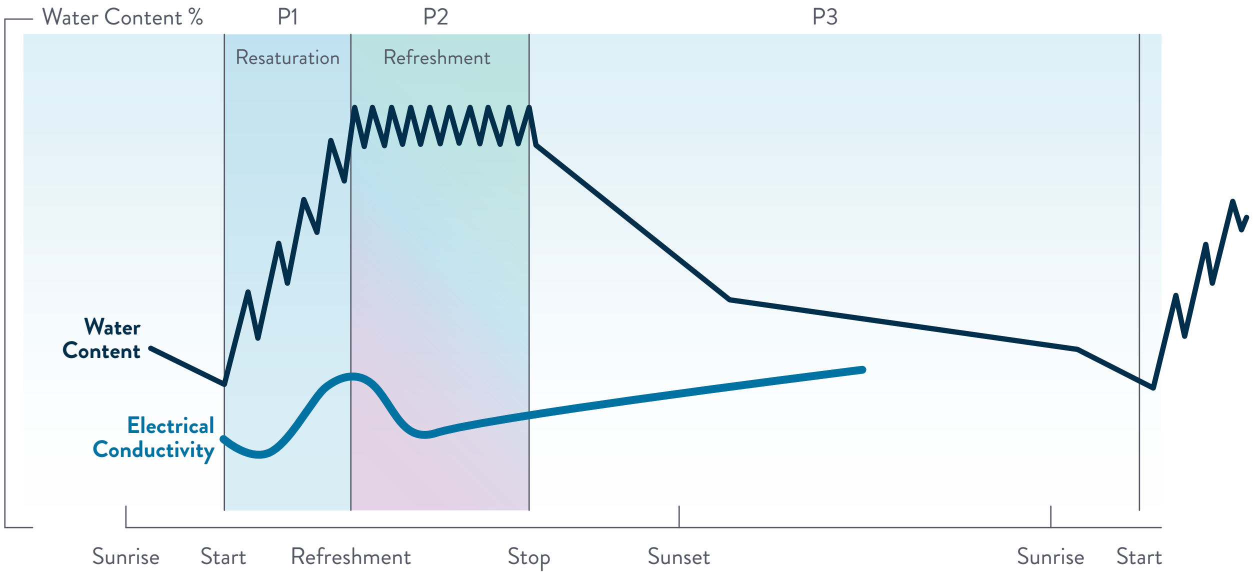
PEAT



Lower-frequency, higher-volume irrigation strategy: Peat-based mixes were historically very common in both unregulated and commercial cannabis production. They have begun to fall out of favor in commercial situations, with coir and rock wool taking the lead due to the greater precision which those options afford in managing substrate.

Peat can hold as high a volume of water as coir, but the portion of nonavailable water is greater. Sphagnum fibers are softer than coir, and cannot support as much weight. Inclusion of expanded mineral, wood fiber, or aged bark help to maintain proper aeration in those mixes.

FIGURE 2: Sample Watering Frequency Using Rock Wool



Source: Adapted from Best Practice Guidelines for Greenhouse Water Management, Grodan 2016

Peat mixes are almost always used with a high percentage of perlite in order to increase aeration of the mix, but that also decreases water retention. Other amendments include organic composts, nutrient charges, vermiculite (less common), aged bark/sawdust, and sand.

Peat mixes are a very wide-ranging category. Peat-lite mixes revolutionized the greenhouse industry back in the 1960s, as they greatly reduced costs for transporting substrate due to its light weight. Peat-lite mixes are made from a high proportion of Canadian sphagnum moss similar to the standard horticulture, with a density of 140 to 180 g/L. Peat may also be amended with various minerals and organic matters, making the mix much denser (200 to 400 g/L) with higher water retention and lower aeration.

Living soils, which blend decomposed organic ingredients (such as various compost), reproduce a natural edaphic environment with diversified microflora. The irrigation management approaches for peat-lite and living soil mixes are different, as the dynamic between water retention and aeration is much different.

WATER CULTURE

Constant application, low-volume: Plants' roots are submerged in solution, and growers typically top off the solution once or twice a week before a complete solution replacement.

Often built using a recirculating system, water culture is considered the most water-efficient cultivation technique. However, due to the high degree of sophistication required to build, operate, and maintain a water culture system, it is not an approach often used in large-scale commercial cannabis cultivation.

Understanding Substrates: When Soil Is Not Soil

It is rare to use amendments (e.g., perlite, sand, sawdust/bark, vermiculite, diatomaceous earth) on their own to grow cannabis. Peat and coco will generally be used as bases for amendments added to achieve an optimal moisture and aeration profile.

Comparatively, rock wool is always used on its own without any amendments, unless for the exception of instances where a rock wool cube is placed atop a coconut coir slab as is common in tomato, cucumber, or pepper greenhouses.

While soilless media is often referred to as soil, it is important to distinguish between the two: Soilless mixes contain no field soil, but typically one or more components like peat, coir, bark, perlite, or vermiculite.

Often, what may be referred to as "living soil" is actually soilless media, but with a highly variable mixture of different organic amendments. In opposition to hydroponics, where most or all of the nutrients for the plant are dissolved in water, all or most nutrients in living soil come from the breakdown of organic matter in the root zone. Thus, living soil can contain some percentage of field soil, or may be soilless substrate.

The two primary water culture systems are:

- DEEP WATER CULTURE: Plants roots are suspended in nutrient solution which is oxygenated with an airstone to allow for root growth. Individual plants are often grown in large (2 to 5-gallon) buckets connected by PVC piping; and
- AEROPONICS: Plant roots are suspended in the air (under some cover to prevent light infiltration). The roots are misted extremely frequently (i.e., 5 to 15 or more times hourly) with small pulses of nutrient solution.

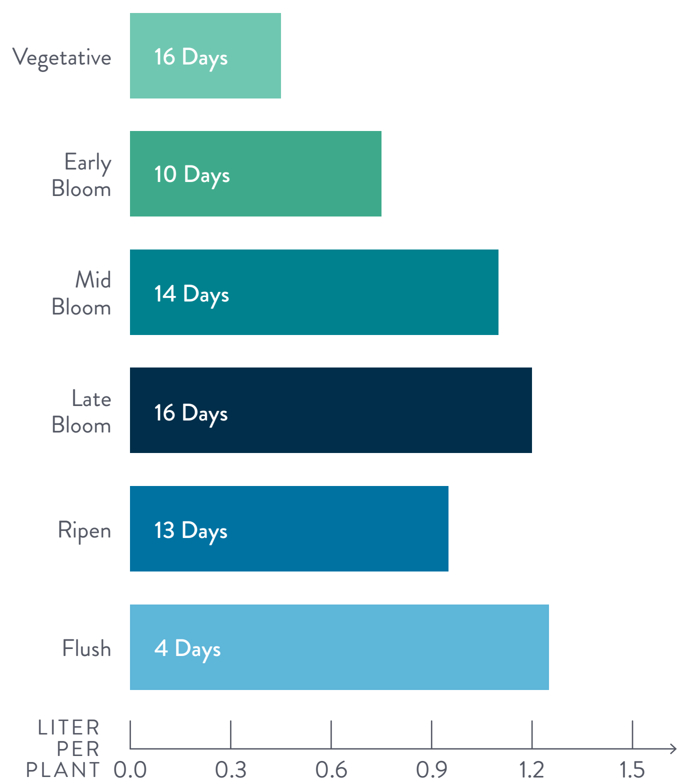
Water Use at Different Stages of Plant Growth

As demonstrated from a trial run in Quebec (Figure 3), irrigation scheduling was determined by using a tensiometer in conjunction with moisture release curve, so water use and the moisture content of the substrate was driving irrigation.

The graph is only intended to show the general water usage at different stages of growth. As the crop develops, water use increases until the ripening stage, where growers may induce drought stress on the crop. The response from the plant is supposed to increase inflorescence, dry weight, and potency.[7] There remains limited data to support it, but the practice is documented in published studies of cannabis cultivators. Water use peaks in the final stage just before harvest, when the plants are commonly flushed with the goal of eliminating any potential contaminants or adulterants before harvest.[8] Due to the industry's stringent testing requirements, permitted growers may use more water in the final stage than growers in the illicit market whose crops are not tested.

FIGURE 3: Minimum Water Usage

Indoor Cultivation 3 Gallon Pot ½ Plant/ft²



Based on Figure 3, the annual water consumption of an indoor operation would be approximately 80 to 100 gallons/plant or 40 to 50 gallons/feet² of growing area depending on the runoff percentage practices of the operator.

7. Caplan,D., Dixon, M., Zheng, Y., Increasing Inflorescence Dry Weight and Cannabinoid Content in Medical Cannabis Using Controlled Drought Stress, HortScience , May 2018

8. This practice has been shown to be largely ineffective at reducing concentrations in plants by the University of Guelph in 2017: Results "showed that the intended purpose of flushing to reduce nutrient concentrations within the bud has no effect. These data show that for the last two weeks of the flower cycle for cannabis, it was possible to use no fertilizer water for irrigation with no significant impact on yield while saving input costs on fertilizer."

Water Insecurity Risks

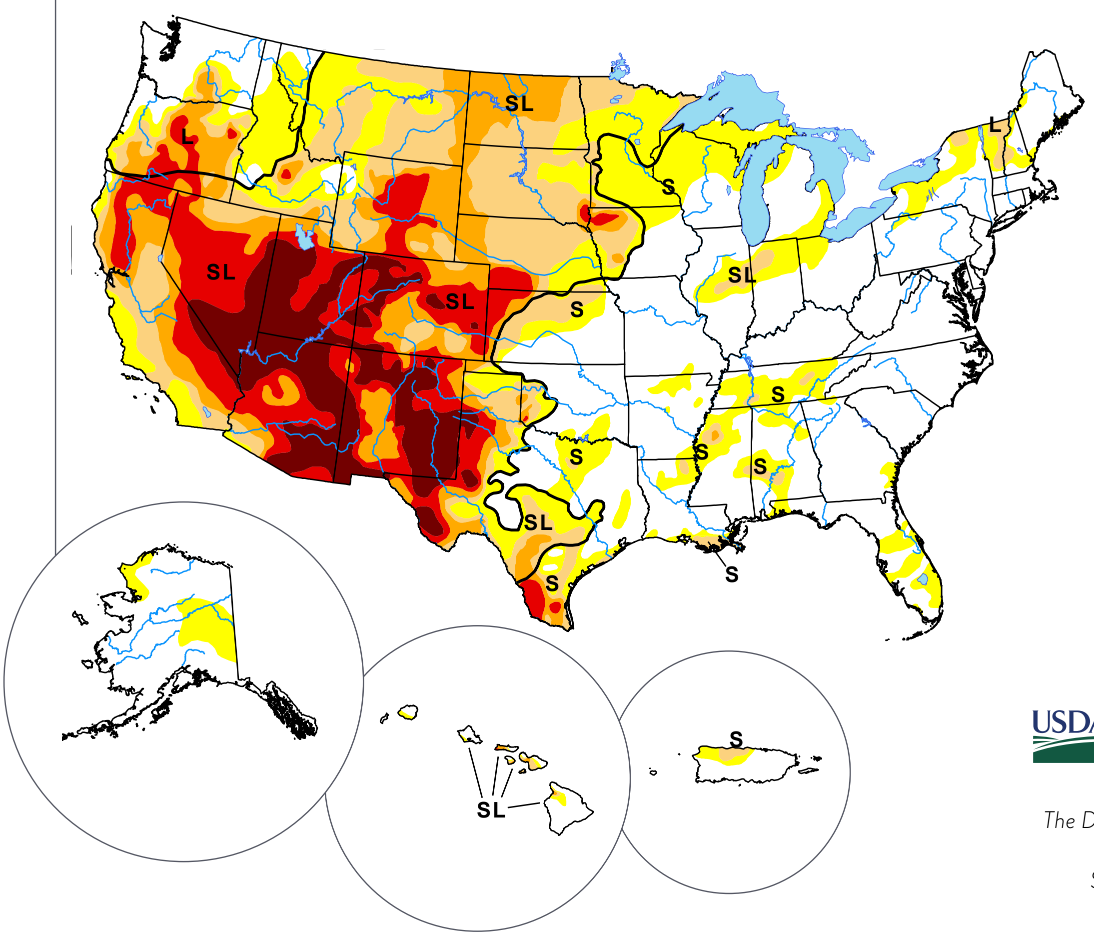
As Drought Conditions Worsen, Risks Rise in America's Most Productive Cannabis Regions

According to NASA, 2020 was the hottest year recorded in the United States since recordkeeping began in 1880; globally, the seven-warmest years recorded have all occurred since 2014. The changing climate is fueling the worst drought experienced in the U.S. in decades, accelerating water scarcity in many parts of the country while driving new urgency to address water use in cannabis cultivation.

Ideal environmental conditions have historically made the western states well suited for outdoor cannabis cultivation, but those states now face the most acute drought conditions in the country. Arizona, California, Colorado, Nevada, New Mexico, and Oregon (which collectively account for 71% of the nation's total cannabis

FIGURE 4: Drought Conditions in the United States

Feb. 16, 2021, Released Thursday, Feb. 18, Valid 7 a.m. EST



DROUGHT IMPACT TYPES

~ Delineates dominant impacts

S Short-Term, typically less than 6 mo. (e.g. agriculture, grasslands)

L Long-Term, typically greater than 6 mo. (e.g. hydrology, ecology)

INTENSITY

- **None**
- **D0 Abnormally Dry**
- **D1 Moderate Drought**
- **D2 Severe Drought**
- **D3 Extreme Drought**
- **D4 Exceptional Drought**

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary.

Source: United States Drought Monitor

FIGURE 5: Severe Drought Cycles in the United States

Percentage of the Country Experiencing D3-D4 Level Drought (1/4/20 - 2/2/21)

Source: United States Drought Monitor

supply, both legal and illicit) are facing severe to exceptional drought conditions according to the National Oceanic and Atmospheric Administration's Drought Monitor.[1]

Nationally, during peak drought cycles approximately one-quarter of the country experiences extreme or exceptional drought, as seen in 2002 (23%), 2012 (24%), and early 2021 (22%).

Amidst the current prolonged and historic drought, a future of rising costs and tightening access to water are making efficiency an increasingly urgent priority.

As California is the country's largest cannabis producer, the extent of its drought over the past decade has been especially noteworthy. In the decade since 2010, not only did the entire state experience multiple consecutive years of severe drought, but between 2014 and 2017 nearly half the state suffered exceptional drought conditions (e.g., Figure 6).

While the intensity of the drought has eased slightly over the past three years, cannabis growers should assume that the trend toward longer, more acute droughts will be sustained well into the future. They should accordingly build their operations to reflect the changing climate, assuming:

- Longer, hotter and drier summers;

1. *The Drought Monitor has been a team effort since its inception in 1999, produced jointly by each the National Drought Mitigation Center (NDMC) at the University of Nebraska-Lincoln, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Department of Agriculture (USDA).*

FIGURE 6: Drought Conditions for California

(1/4/20 - 2/2/21)

D0: Abnormally Dry

- *Soil is dry; irrigation delivery begins early*
- *Dryland crop germination is stunted*
- *Active fire season begins*

99.4%

D1: Moderate Drought

- *Dryland pasture growth is stunted; producers give supplemental feed to cattle*
- *Landscaping and gardens need irrigation earlier; wildlife patterns begin to change*
- *Stock ponds and creeks are lower than usual*

85.1%

D2: Severe Drought

- *Grazing land is inadequate*
- *Producers increase water efficiency methods and drought-resistant crops*
- *Fire season is longer, with high burn intensity, dry fuels, and large fire spatial extent; more fire crews are on staff*

57.9%

D3: Extreme Drought

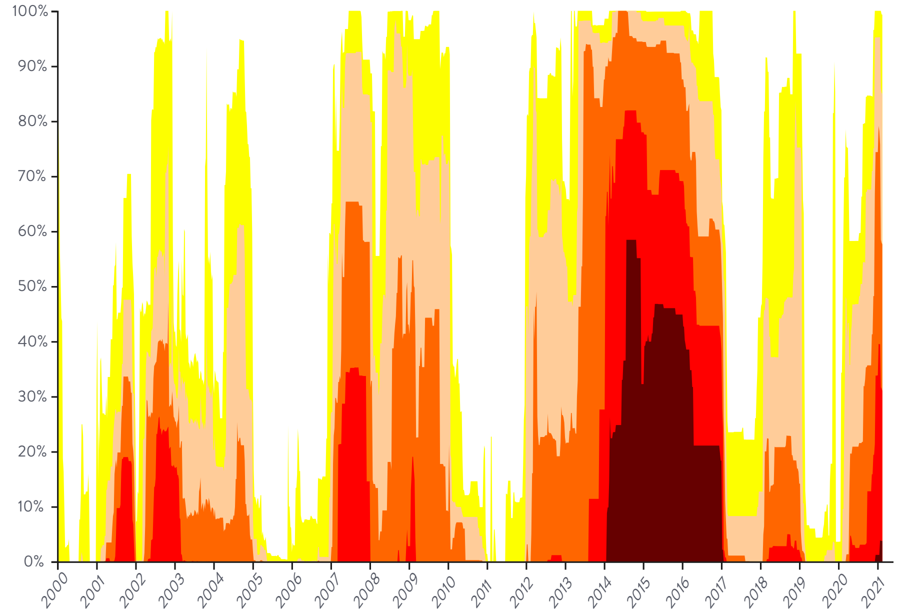
- *Livestock need expensive supplemental feed, cattle and horses are sold; little pasture remains, producers find it difficult to maintain organic meat requirements*
- *Fruit trees bud early; producers begin irrigating in the winter*
- *Federal water is not adequate to meet irrigation contracts; extracting supplemental groundwater is expensive*

31.4%

D4: Exceptional Drought

- *Fields are left fallow; orchards are removed; vegetable yields are low; honey harvest is small*
- *Fire season is very costly; number of fires and area burned are extensive*
- *Many recreational activities are affected*

3.8%



Source: *National Integrated Drought Information System*

- New restrictions on water access, water discharge volumes, and minimum effluent quality standards/monitoring as groundwater sources become more scarce;
- That states like California will iteratively tighten building codes to increase energy efficiency, reduce waste, and preserve indoor and outdoor air quality via mechanisms like Title 24, the state's triannually updated Building Energy Efficiency Standards (such regulations will have implications for HVAC, humidity control, and other environmental management systems which impact water use in the grow environment);
- More expensive water supply from public systems;
- Increased cooling demand for indoor and greenhouse growers to offset higher loads; and
- Higher operational expenses for temperature control and water management systems

Additionally, due to limited research, impacts of drought stresses on a cannabis plant's maturation and cannabinoid production remains poorly understood. For the thousands of outdoor growers in the western states, a drier, hotter future could have significant implications for which cultivars they grow, and what techniques they will need to adopt to optimize both crop yield and harvest quality.

Water Benchmarks

The ***Cannabis H2O: Water Use & Sustainability in Cultivation*** report is the combination of two original works: The first includes the U.S. cultivation estimates for both the illicit and legal markets (with all estimates based on New Frontier Data's analysis of legalized production in legal states, and careful assessment of illicit activities in non-legalized markets); the second work incorporates water-performance indicators based on data submitted by cultivators to Resource Innovation Institute's Cannabis PowerScore resource benchmarking platform. The estimated total production volume, flowering canopy, and total U.S. cannabis industry cultivation water use are respectively derived from those two sources.

Background & Methodology

This section of the report provides benchmark performance standards, and explores potential causes of performance variation. As described on page 4, all analysis herein has been performed using data aggregated by RII's Cannabis PowerScore platform.

The data here comes from multiple sources. The primary source is the Resource Innovation Institute's Cannabis PowerScore resource benchmarking platform. Cultivators and supply-chain partners throughout North America use PowerScore to submit facility details such as square footage of flowering canopy, amount of product produced, and annual resource consumption data, to receive a competitive performance benchmark comparing their operation's KPIs to others growing like them.

In summer 2020, RII expanded its Technical Advisory Council to include a Water Working Group to establish a scientific understanding of how (and how much) water is used for cannabis cultivation; the aim was to give cultivators confidence in taking steps to be more efficient, and help industry leaders, governments, and media be more accurately informed about the range of water practices in today's regulated market. Members include cultivators, regulatory agencies, academic researchers, equipment manufacturers, engineers, and substrate suppliers.

Members of the Water Working Group offered RII recommendations to expand PowerScore to accept new information about water management practices, to better inform new reports and KPIs describing resource applications, storage, and usage. RII also developed a data transfer protocol, and PowerScore was upgraded to accept submissions of portfolios of facility data, so that larger batches of self-reported data from regional regulatory agencies could be analyzed.

In autumn 2020, RII integrated data from a variety of sources, ensured representation across various locations and methods, and standardized metrics to enable a range of performance.

The Berkeley Cannabis Research Center, Resource Innovation Institute, and New Frontier Data cooperatively consolidated, analyzed, and formulated observations about the information. New Frontier Data used its extensive knowledge of the industry to help summarize the overall market, contextualize the data, and develop industry forecasts.

The teams collaborated to evaluate the data findings and articulate the most salient items to benefit readers of this report, intending to provide the greatest impact for operators, water suppliers, investors, and policymakers.

About Cannabis PowerScore

PowerScore is an online software suite of tools including a survey, facility-level performance benchmarks, dashboards, and reports. The PowerScore survey collects self-reported performance data and cultivation characteristics (e.g., annual production, monthly water consumption, flowering canopy area, cultivation approach, and substrate), to generate a performance benchmark summarizing up to 14 key performance indicators (KPIs) at the facility level. Users benefit by instantly being shown their operation's ranking relative to the rest of the PowerScore's database, through the Ranked Data Set. All data is kept anonymous.

Study Limitations

PowerScore data has potential limitations which the report authors have addressed with data quality protocols described in this section. This report analyzes self-reported data from PowerScore; user-submitted data carry the risk of being either submitted with errors, or with a different interpretation than what the survey creators intended. Since separate and dedicated water-use metering is not always available to growers, monthly water-use submissions might include water from noncultivation-related occupancy or process. For example, while a user might report monthly water usage for a facility, reported annual consumption of the operation could include water consumption for processes other than cultivation, leaving undetermined the portion of water used for cultivation alone.

In an attempt to minimize errors from self-reported data, the report's authors have removed outlier submissions with the guidance of members of RII's Technical Advisory Council and Water Working Group. Facility records using application rates and outputs from water management systems are considered records of the highest quality; those using best guesses were removed from the dataset when records noted the characteristic.

In most cases, users submit data to PowerScore on their own accord, and are not compelled by their regulators. While in most regions power and water consumption information is not required by regulators, there is a growing trend in states and municipalities to mandate reporting. Beginning in summer 2020, cultivators in Massachusetts began complying with energy and water-reporting requirements, and some facilities in the Ranked Data Set contain the required information. For records voluntarily submitted, there is potential for a submission bias wherein the data overrepresents cultivators who are actively engaged in improving their environmental performance. Future iterations of this work will continue to utilize larger and less potentially biased datasets, as more states' regulators require benchmarking and reporting of the industry's resource efficiency metrics. Likewise, future reports will also feature aggregate data from a broader geographical distribution of data.

The analysis in this report focuses specifically on facility-level water used in cultivation. It is important to note that there is additional water embedded within the supply chain and other processes that is not accounted for in this analysis. The estimates in this report do not include other areas such as the water used for controlling environmental conditions with heating, cooling, and humidification equipment, post-harvest processing (i.e., production of extracts and derivatives), irrigation water production and treatment outside the facility, or water used for power generation equipment.

Assumptions & Model Estimations

Developing market estimates for national water use estimates for cannabis required key assumptions due to the data limitations in the cannabis industry. Key data challenges include:

1) **Limited production data availability:** Very limited information is available about production practices in the illicit market which accounts for the majority of cannabis grown in the U.S. In the legal markets, data collection on production varies widely across markets. As such, the model relies heavily on consumption data and the limited data available from regulated markets (i.e., Colorado) to estimate overall production volumes.

2) **Widely divergent cultivation practices:** Across the legal and unregulated markets, growers use widely varied practices to cultivate practices. Differences include:

   - **Number of harvests per year.** Some growers only harvest once a year, others, especially in indoor facilities, can harvest five or more times per year
   - **Plant sizes.** Correlated to harvest frequency, growers with low harvest frequency will produce crops that can be 10 feet tall or taller, whereas plants in a frequent harvest facility may only reach 3-4 feet.
   - **Substrate variance.** The substrate, or medium in which the crop is grown, varies widely, from soil and peat, to rockwool and hydroponics. Each substrate used requires different watering techniques, adding further complexity to estimating average water use.
   - **Plant density.** Space-constrained facilities often pack the plants tightly together, whereas outdoor facilities in particular tend to have wide spaces between plants. This significantly influences both the estimates for water used and the yields per square foot.

3) **Changes in production practices for smokable flower versus value added (extract-based) products.** Historically, cannabis buds were sold for smoking (loose flower and pre-rolls) whereas the plant's leaves and trim from preparing the buds was sold for extraction. However, as the market for extracts has grown, some growers are now producing plants which are fully intended for the extracts market. Production for extraction-only remains a small proportion of all cultivation in the U.S.

Assumptions

Production volume per dollar of revenue earned.

Based on the sales revenue data collected, we developed an estimate for the volume of production required to meet the retail demand. This estimate was based on the production volumes reported in Colorado, the country's most mature cannabis market.

KEY ASSUMPTION: The revenues earned in Colorado per pound of cannabis produced are an effective proxy for production practices across the country due to the longitudinal data available, and the mix of cultivation facility types used in the state.

Pounds of smokable flower produced.

The estimates for pounds produced are for smokable flower only. It does not include the biomass weight produced from trim of leaves. The smokable bud estimates are based on the cured finished product, not on the wet weight at the time of harvest.

KEY ASSUMPTION: The trim and leaf used to produce extracts is from the same plants from which the smokable bud is harvested. As such the square footage used to produce smokable flower is the same as what is used to supply the extract market.

Percentage of production for import/export.

The illicit market accounts for most of the cannabis consumed in the U.S. Most states are net importers of cannabis, relying on exports primarily from California. Based on analysis of data from the U.S. government's cannabis eradication program, and inputs from industry and cannabis policy experts, we developed estimates for total production in each state based the estimated volume of domestically produced and imported cannabis.

KEY ASSUMPTIONS:

- Cannabis imports only apply to the illicit market. All legal market products are produced within the states where they are sold.
- The volume of imports declines over time as legal markets are established in each state.

Distribution of facility types in each state.

Based on analysis of licensing data (where available) and discussions with in-state operations experts, we estimated the proportion of indoor, greenhouse, and outdoor facilities in each state. Generally, states which experience more extreme weather were more likely to have indoor and greenhouse facilities, whereas those in more temperate regions were more likely to grow outdoors.

KEY ASSUMPTION: The proportion of indoor, greenhouse, and outdoor facilities in each state are similar in the legal and illicit production facilities within each state.

Average yield per square foot of flowering canopy.

To determine the average yield per square footage and facility type, we reviewed existing market data and polled licensed cannabis producers operating in different U.S. markets. These estimates were used to great the national aggregated estimate for total square footage used to grow cannabis. Due to the limited number of inputs, the estimated values can significantly influence the total national estimates for production scale.

Square footage of Flowering Canopy vs. Square Footage of Total Canopy or Total Facility Size.

There are three common metrics used for cannabis facilities:

- **Flowering canopy:** The area used to grow the plants during their final stage of growth before harvest.
- **Total Canopy:** The square footage used to grow plants during the seedling, vegetative, and flowering stages.
- **Total Facility Size:** The total size of the cultivation facility, including canopy, production areas, offices, etc.

KEY ASSUMPTION: For purposes of this report, the canopy areas referenced are for *flowering canopy only* since the surveyed growers measure their yields per square foot of flowering canopy.

Water Data Sets

Three sets of data are included in the PowerScore analysis: the national PowerScore Ranked Water Data Set, the Northern California 2019 dataset, and the Michigan 2020 dataset.

The use of these datasets is opportunistic, yet also provides a good snapshot of current cannabis production. Each dataset has its own strengths. The national PowerScore data is broadly representative of cannabis production across the United States, and provides data from many of the largest producing regions. The Northern California data is by far the largest dataset, and therefore may provide the most reliable picture of regional water use. The Northern California data is nevertheless important, as that area still contains the majority of California's permitted cannabis farms, and likely a majority of unpermitted farms also. The Michigan dataset provides a glimpse into water use in a rapidly changing new market.

> The use of these datasets is opportunistic, yet also provides a good snapshot of current cannabis production.

POWERSCORE RANKED WATER DATA SET

The PowerScore Ranked Water Data Set contains 44 total records with complete water KPIs. These records include indoor facilities, greenhouses, and outdoor farms in nine states (i.e., California, Colorado, Illinois, Maryland, Massachusetts, Ohio, Oregon, Vermont, and Washington).

Each PowerScore record reports flowering canopy square feet, annual production, and gallons of water both stored and applied by month.

Also provided is limited plant count data, with plant counts extrapolated from total canopy square feet (per plant gleaned from the Northern California 2019 Data Set for mixed-light and outdoor farms).

Within the set of 44 facility records, there are several subgroups of facilities:

The PowerScore Ranked Water Data Set is biased towards smaller operations, with less representation of larger farms. The average flowering canopy area is 44,900 square feet for outdoor farms, 10,400 square feet for greenhouse operations, and 6,210 square feet for indoor facilities in this data set. That farm size is significantly smaller than farm size data in California. Analysis by UC Berkeley using government data and aerial imaging analysis shows that larger farms make up a significantly higher proportion of California's total canopy than do smaller ones: Farms with over 30,000 square feet account for 71% of permitted canopy, and 35% of unpermitted farms.

The report's analysis of total water use was based on the distribution of square footage in each group, not the percentage of PowerScore records in each category.

FIGURE 7: PowerScore

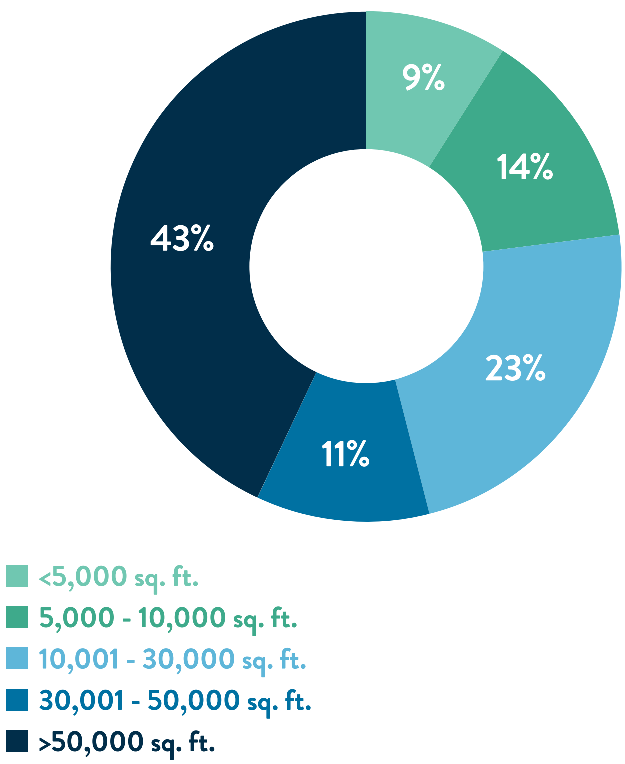
Flowering Canopy Square Feet	PowerScore Ranked Water Data Set	California Percentage of Canopy Square Footage by Farm Size		
		California Permitted Farms % sq. ft.	California Non-Permitted Farms % sq. ft.	California Average % Total sq. ft.
<5,000 SF	**51%**	2%	16%	**9%**
5,000 - 10,000	**13%**	12%	16%	**14%**
10,001 - 30,000	**15%**	14%	32%	**23%**
30,001 - 50,000	**13%**	11%	10%	**11%**
>50,000	**8%**	61%	25%	**43%**

Figure 7 illustrates the distribution of PowerScore Ranked Water Data Set records by flowering canopy size, compared against UC Berkeley's assessed distribution of permitted and non-permitted California farm sizes.

Nearly half of the PowerScore Ranked Water Data Set records are for indoor facilities, with the data regionally concentrated primarily between the Pacific Northwest and New England.

For indoor facilities, water use is more heavily influenced by the plants than by the outdoor environment, due to the greater insulation from exterior conditions. Consequently, limited variance in water use is expected between identically designed indoor facilities across the country.

FIGURE 8: California Average % Total sq. ft.



However, the wide variance in climatic conditions nationally means that exterior conditions will have far greater impact on resource use in greenhouse and outdoor operations. As such, while this analysis provides an illustrative view into the industry's water use, and identifies opportunities to increase water efficiency, it does not capture the regional variance of non-indoor facilities across the country.

RII will continue to work to capture data from nationally distributed operators as legal markets extend across the northern states (e.g., Michigan, Illinois, Montana) which experience mild summers and long, cold winters, across southwestern states (e.g., Arizona and New Mexico) with warmer, drier conditions, and into southern states (e.g., Florida, Georgia, Louisiana, Oklahoma) which experience hot, humid conditions.

The PowerScore Ranked Water Data Set records represent facilities using several cultivation techniques that could influence water usage for cultivation.

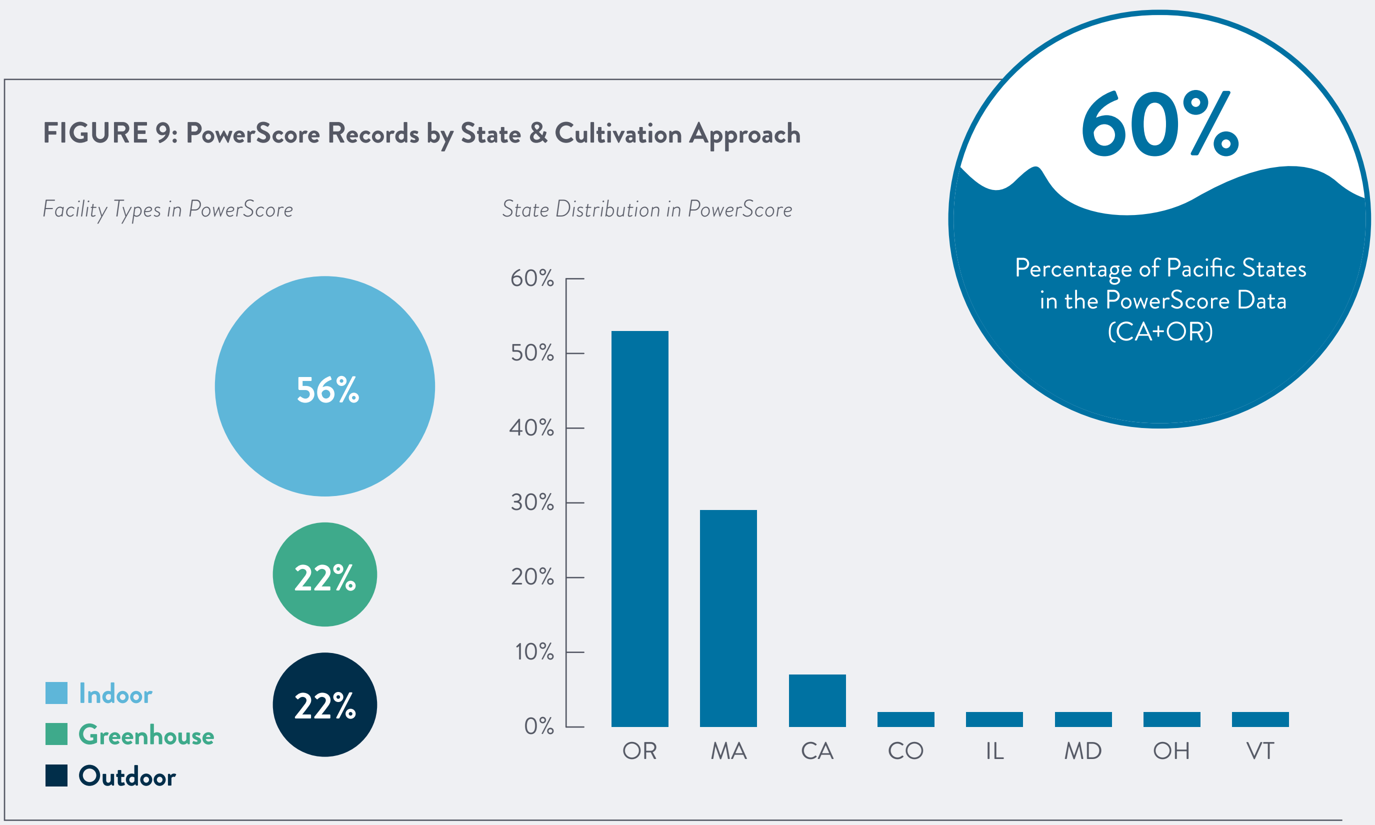


FIGURE 9: PowerScore Records by State & Cultivation Approach

The PowerScore Ranked Water Data Set records represent facilities using a variety of water sources, including potable and natural water sources.

FIGURE 10: National PowerScore Water Sources

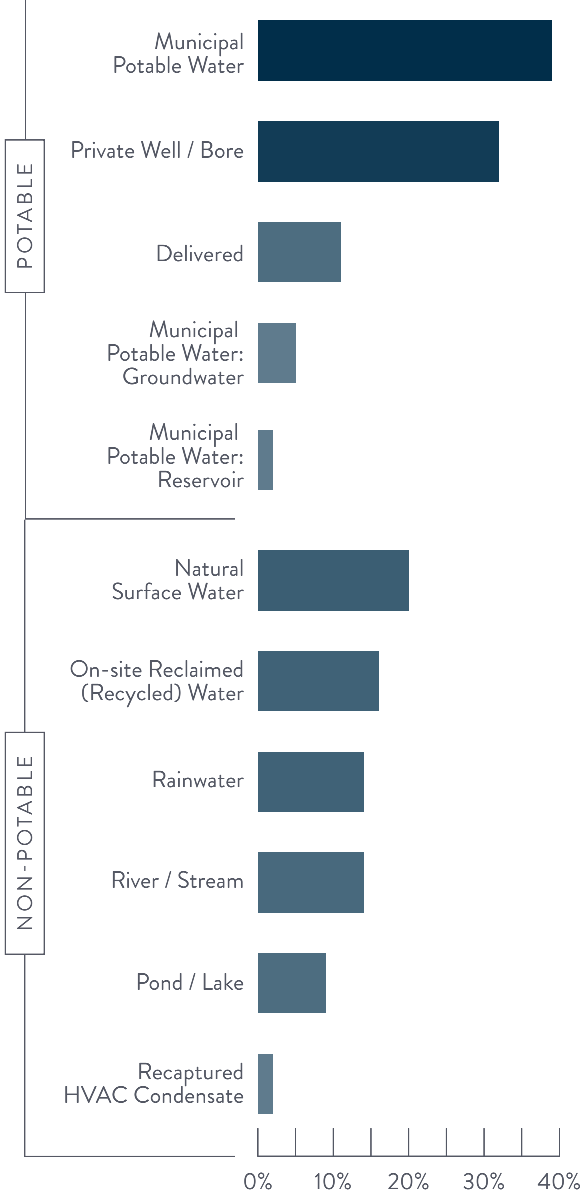


FIGURE 11: Potable Water Sources

by Facility Type

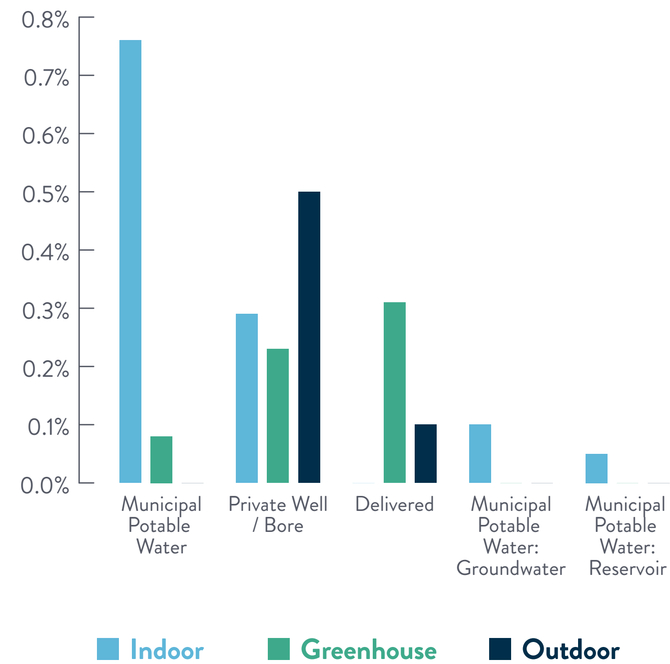
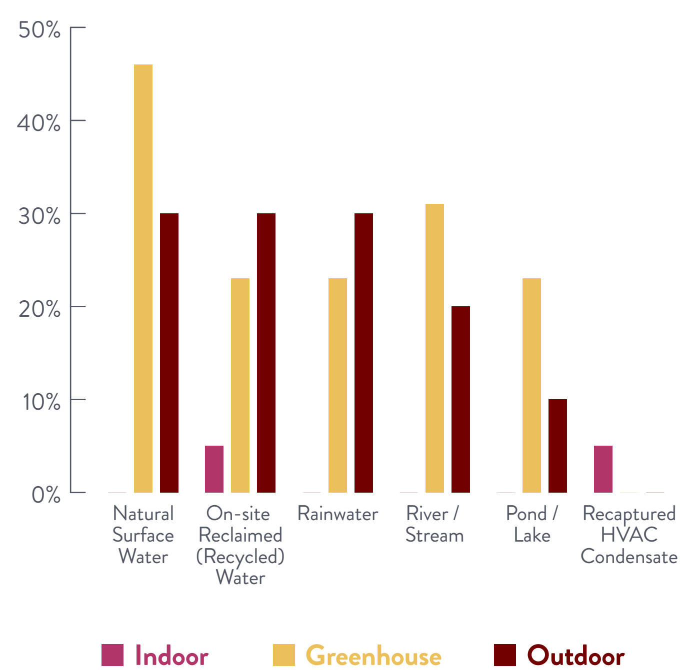


FIGURE 12: Non-Potable Water Sources

by Facility Type



NORTHERN CALIFORNIA 2019 DATA SET

The Northern California 2019 Data Set contains 618 records covering greenhouses and outdoor farms in Mendocino, Humboldt, Trinity, and Sonoma counties that have received cultivation permits from the state of California. The data was obtained via a Public Records Act request to the California Water Boards. Each record reports a plant count, total canopy square feet, and gallons of water stored and applied monthly. The dataset does not contain production data.

The Northern California 2019 Data Set is biased towards small- to medium-sized operations, and has less representation of larger farms. In the data set, the average flowering canopy area for outdoor farms is 12,650 square feet, and 10,200 square feet for greenhouse operations.

The Northern California 2019 Data Set has a concentration of greenhouse facilities (i.e., operations using supplemental light).

FIGURE 13: California Cultivation Facility Data
by County

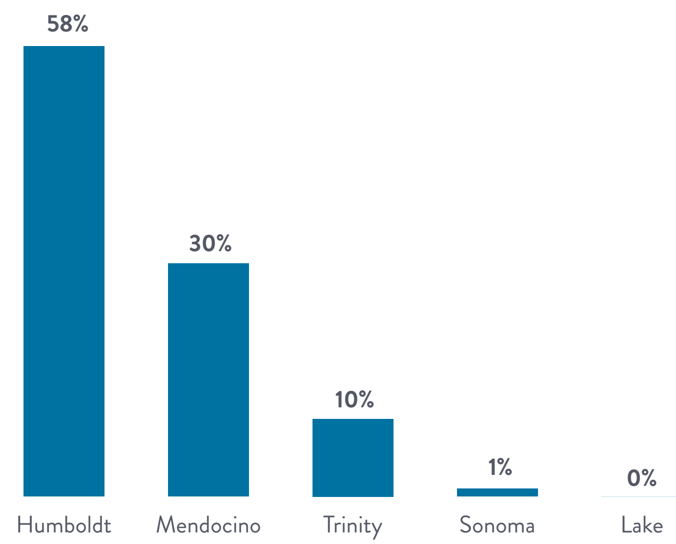
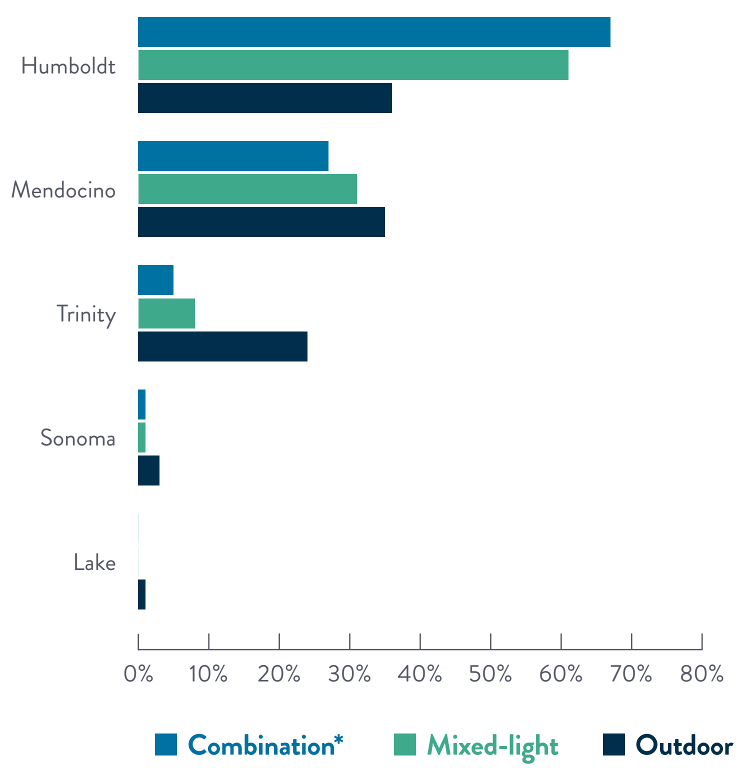


FIGURE 14: California Cultivation Facility Type
by County



* *Farms with canopy area both outdoors and in mixed light environments*

FIGURE 15: California Average Canopy Area
by Facility Type

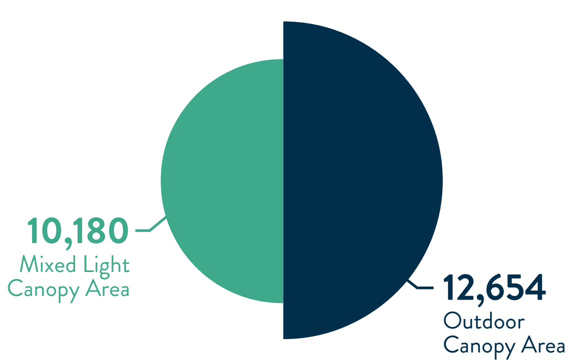


FIGURE 16: California Primary Source of Water

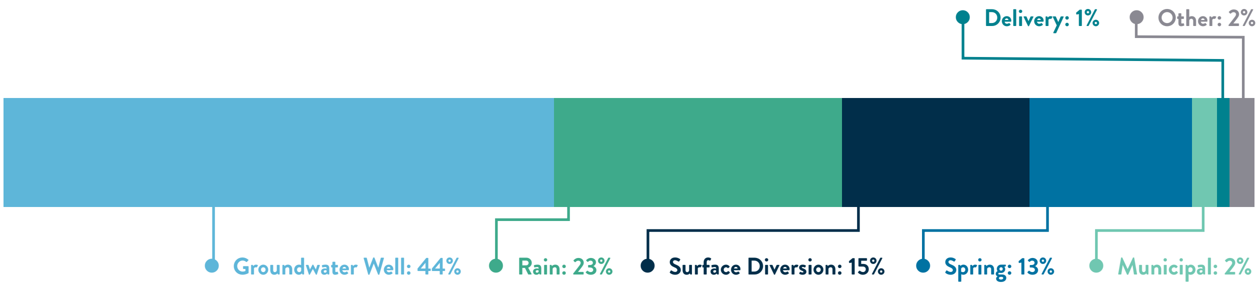


FIGURE 17: California Secondary Source of Water

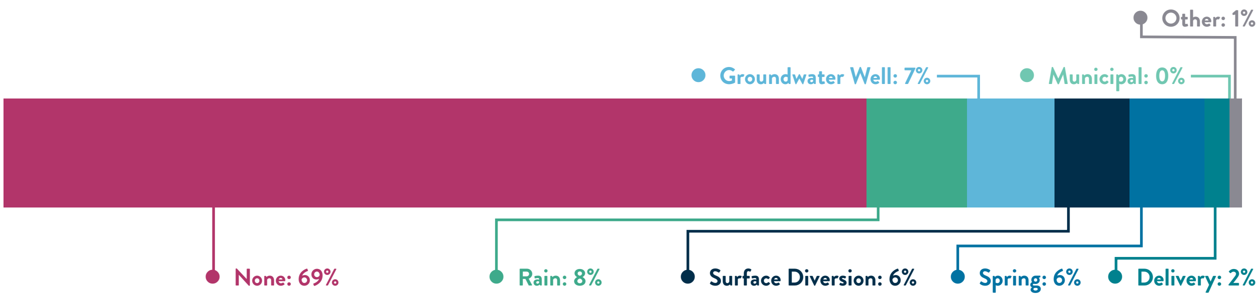
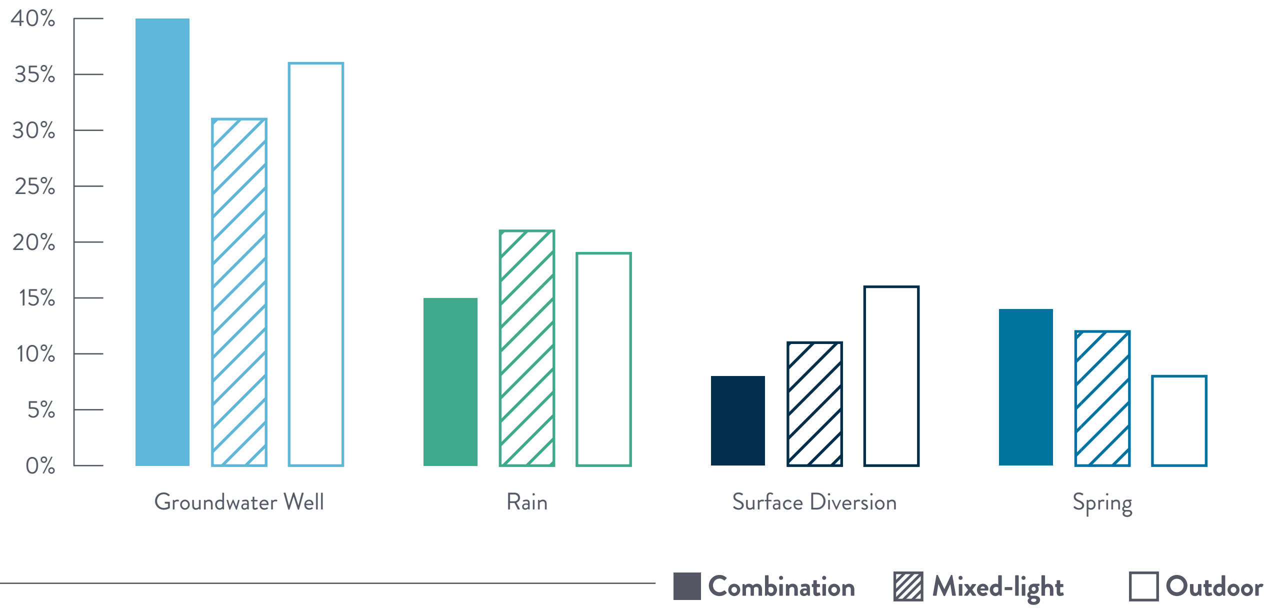


FIGURE 18: California Primary Sources of Water

by Facility Type



MICHIGAN 2020 DATA SET

The Michigan 2020 Data Set represents 12 indoor facilities licensed in Lansing, Michigan. The indoor facility records report gallons of water applied by month of year. All facilities in the data set are served by the local public water system. Information about storage infrastructure is undetermined.

The dataset does not provide plant count data, but regulations in Michigan limit plant count:

- CLASS A – 500 Plants Med/100 Plants for Adult Use (AU)
- CLASS B – 1,000 Plants Med/500 Plants for Adult Use (AU)
- CLASS C – 1,500 Plants Med/ 2,000 Plants for Adult Use (AU)
- EXCESS LICENSE – 2,000 Extra Plants (Medical)

Class C licenses are the license type for 92% of the records in the Michigan dataset.

Water Sources

A majority of mixed-light (50%) and outdoor (56%) facilities in Northern California use groundwater wells as water sources. Most (61%) mixed-light facilities also use tanks of stored water, and nearly a quarter (23%) use rain as a water source. Six in 10 mixed-light facilities (61%) and nearly half of the outdoor facilities (48%) use tanks, while one-quarter (23%) of mixed-light facilities and 17% of outdoor farms use rain as a water source.

It is worth noting that facilities using rainwater often collect the rainwater during the offseason, due to the limited rainfall during summers when the crops are being grown.

All indoor facilities in the PowerScore Ranked Data Set use potable water for source water. No indoor facilities use natural surface water, but 5% use on-site reclaimed water from use of recovered condensate from HVAC and dehumidification equipment. No indoor facilities in the PowerScore Ranked Data Set rely on rain as a water source, and none has water delivered to their facility.

Growers in other parts of the country, especially the water-rich Northeast and Midwest states are more likely to rely on public water than invest in building onsite groundwater supplies. Furthermore, these areas are less likely to see major water disruptions due to drought and are therefore less likely to need redundancy systems to back up their primary water supply.

Key Benchmarks

The table below shows four key benchmarks for tracking a cultivation organization's water performance by cultivation approach from PowerScore, California, and Michigan. Ranges are used to describe water performance of varying cultivation approaches. More detail is provided on each key performance indicator in the following sections:

1) **Water Productivity**
2) **Water Efficiency**
3) **Water Demand**
4) **Water Storage**

NOTE: LIMITATIONS OF MEASURING WATER USE PER PLANT

Early efforts over the past decade by state environmental agencies to quantify water efficiency of cannabis production facilities used unit metrics such as gallons per plant as a baseline for typical performance. However, with the extremely broad range of planting densities —which can range from as low as 300 plants per acre in outdoor farms to as many as thousands of plants per acre indoors — the plant size and duration of the cultivation period range so widely that they render any water-use per plant comparison meaningless. Therefore, an attempt has been made to develop efficiency measures that are comparable across plant densities.

FIGURE 19: Key Metrics on Cultivation Facility Water Use

PowerScore

	Indoor	Greenhouse	Outdoor
Water Facility (Gallons/sq. ft.)	198	79.9	10.8
Average Monthly Usage	87,436	27,833	25,500
Total Annual Usage	649,000	334,000	306,000
Water Productivity (grams/gallon)	3.74	1.88	3.13

California Cultivation Facilities

	Combination	Mixed-Light	Outdoor
Water Facility (Gallons/sq. ft.)*	11.4	14.9	11.3
Average Monthly Usage	15,921	15,104	12,429
Total Annual Usage	206,977	196,346	161,578
Storage Gallons / Canopy Square Feet	12.2	14.8	9.99
Total Annual Storage	221,403	194,960	174,028

** Collected as applied gallons per square foot.*

Michigan Cultivation Facilities

	Average
Average Monthly Usage	64,629
Total Annual Usage	775,543

Water Productivity (grams/gallon)

Of all metrics relevant to water consumption, water productivity best represents how efficiently a cultivator is using water to produce cannabis. The metric represents a cultivator's cannabis output relative to water input. Over a 12-month period, cannabis output is measured in grams of dry (trimmed) flower produced, with water input measured in gallons of water applied for irrigation. A higher value for water productivity indicates more effective use of water as a resource.

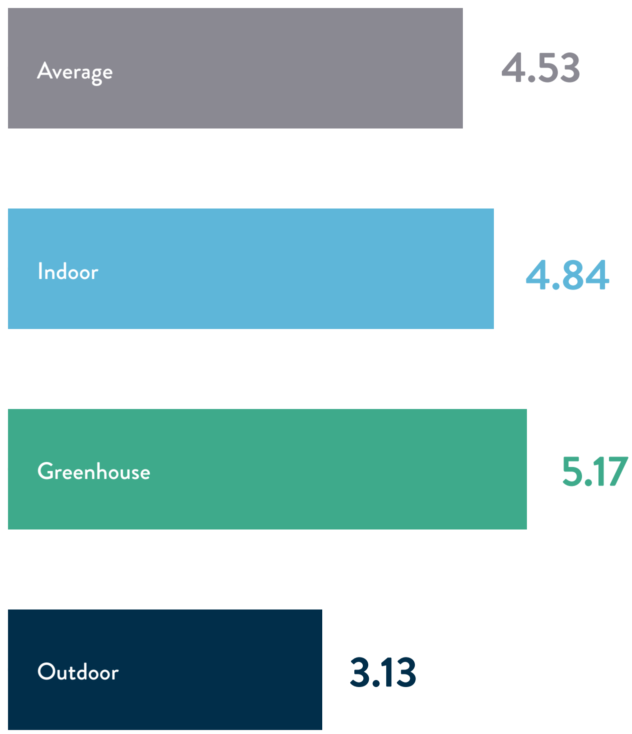
PowerScore Water Productivity (grams/gallon)

Data from the PowerScore Ranked Water Data Set show average water productivities of 4.8, 5.1, and 3.1 grams per gallon for indoor, greenhouse/hybrid/mixed-light,[9] and outdoor cultivation operations, respectively.

The average water productivity of the PowerScore Ranked Water Data Set shows greenhouse facilities achieving the best grams per gallon, using the least amount of water per gram of cannabis produced, closely followed by indoor facilities. Outdoor facilities had the lowest yield per gallon.

FIGURE 20: PowerScore Water Productivity

Grams/Gallon



> The PowerScore Ranked Water Data Set shows greenhouse facilities achieving the best grams per gallon, using the least amount of water per gram of cannabis produced.

9. Facilities are categorized as hybrid type if they are designated as a greenhouse, or if the data for the latest plant growth stage reports using both sunlight and electric light. The average water productivity performance of greenhouses compared to outdoor farms may be influenced by outdoor farms generally including total land area in their flowering canopy area totals; having wider spacing between the plants, they may appear to be more efficient because their farm footprint is much larger than their true flowering canopy area, giving them a much larger denominator.

Water Efficiency (gallons/square foot)

The metric describes a cultivation facility's annual application of water for irrigation per unit of area. A lower value for water efficiency indicates more effective use of water as a resource.

Energy industry professionals are presumably familiar with energy use intensity (EUI), a metric used for characterizing building energy consumption, and often used in benchmarking exercises. While water-use intensity (WUI) is similar, it typically is divided by total (i.e., gross) building area for other kinds of buildings, whereas the version of the metric in question uses flowering canopy (rather than total building area) as the relevant definition of area, as PowerScore also uses for energy KPIs. Canopy is defined as the tray-and-table area used for plant production, not the total area available for planting (excluding all aisles, walkways, and noncultivation areas). Flowering canopy includes only tray-and-table area used for flowering cannabis plants (excluding canopy area for younger plants).

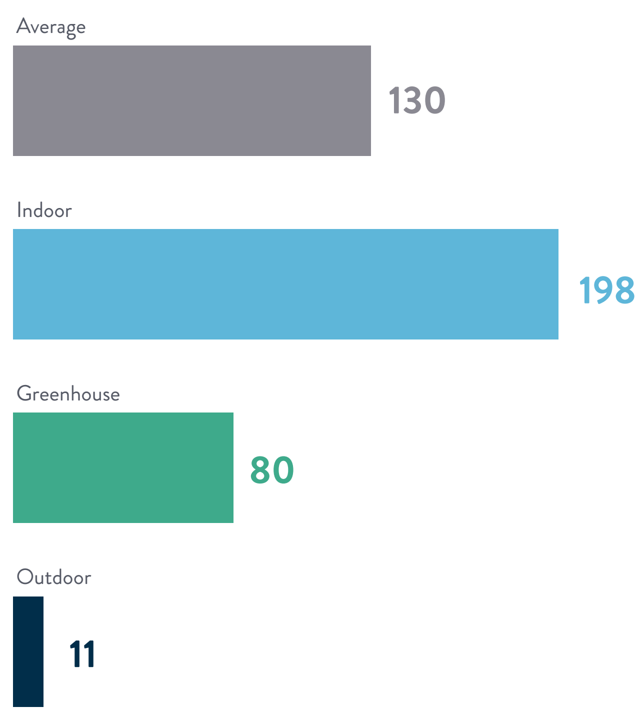
It is worth noting that the reported canopy of outdoor grows is more likely to include non-water-using areas between plants than in greenhouse grows, where the plants are typically more densely planted together. That thereby lowers the water usage by area for outdoor farms, since the area measurement includes a larger overall footprint than is being actually used for cultivation. Additionally, the variability in plant spacing and plant sizes in outdoor farms makes it impossible to create a uniform way to account for the unused space between plants.

Also, when applying any metric with area in the denominator, it is worth considering how a given site's utilization might impact results. Consider a new facility that is still ramping up production, or one that reduces output in response to low prices during the outdoor harvest months: Compared to a facility of identical size and efficiency that operates at 100% utilization, the water efficiency at the lower utilization facility will be lower (despite electricity productivity being the same). The dynamic is likely expressed in some of the Cannabis PowerScore data.

PowerScore Water Efficiency (gallons/square foot)

Data from the PowerScore Ranked Water Data Set show average water efficiencies of 198, 80, and 11 gallons per square foot of flowering canopy for indoor, mixed-light, and outdoor cultivation operations, respectively.

FIGURE 21: PowerScore Water Efficiency
Gallons/sq. ft.



The average water efficiency of the PowerScore Ranked Water Data Set shows outdoor farms attaining the best water efficiency, using the least amount of water per area of flowering canopy.

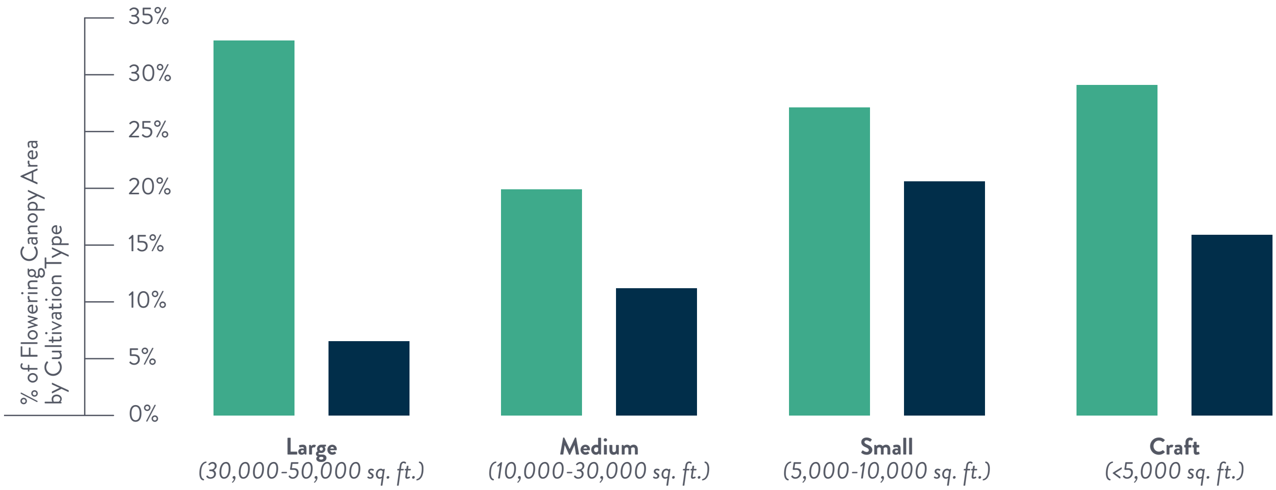
The indoor operations have the highest water use per square foot. At nearly 200 gallons/sq. ft., the PowerScore indoor reported averages are significantly higher than typically seen range between 50-73 gallons/sq. ft. This suggests the PowerScore participants may be running more harvest cycles per year than average, thereby driving up their use.

Northern California Water Efficiency (gallons/square ft)

Data from the Northern California 2019 Data Set show a range of average water efficiencies of greenhouse and outdoor facilities by flowering canopy size. Greenhouses range between 20-33 gallons per square foot of flowering canopy per year, while outdoor operations achieved better average water efficiency values of 6.5-21 gallons per flowering canopy square foot.

FIGURE 22: California Annual Water Use

Gallons Applied per Flowering Canopy Area sq. ft.



Facility Type	Annual Gallons Applied per Flowering Canopy Area			
	Large (30,000 - 50,000 sq. ft.)	Medium (10,000 - 30,000 sq. ft.)	Small (5,000 - 10,000 sq. ft.)	Craft (<5,000 sq. ft.)
Greenhouse	33.0 14 records	19.9 72 records	27.1 123 records	29.1 62 records
Outdoor	6.54 7 records	11.2 26 records	20.6 71 records	15.9 19 records

■ Greenhouse ■ Outdoor

Water Demand (gallons/month)

The metrics herein describe a cultivation facility's water consumption per month, to represent how much water each facility and plant demands as they produce cannabis. There are two kinds of water demand: storage demand, and application demand. Storage demand conveys how much water is held on-site, and can be described using gallons per year and per month. Application demand also describes how much water per year and per month.

The PowerScore Ranked Water Data Set collects both application and storage water demand to understand the related activities of water application and water storage, and to make the data more comparable across all data sets and types of facilities.

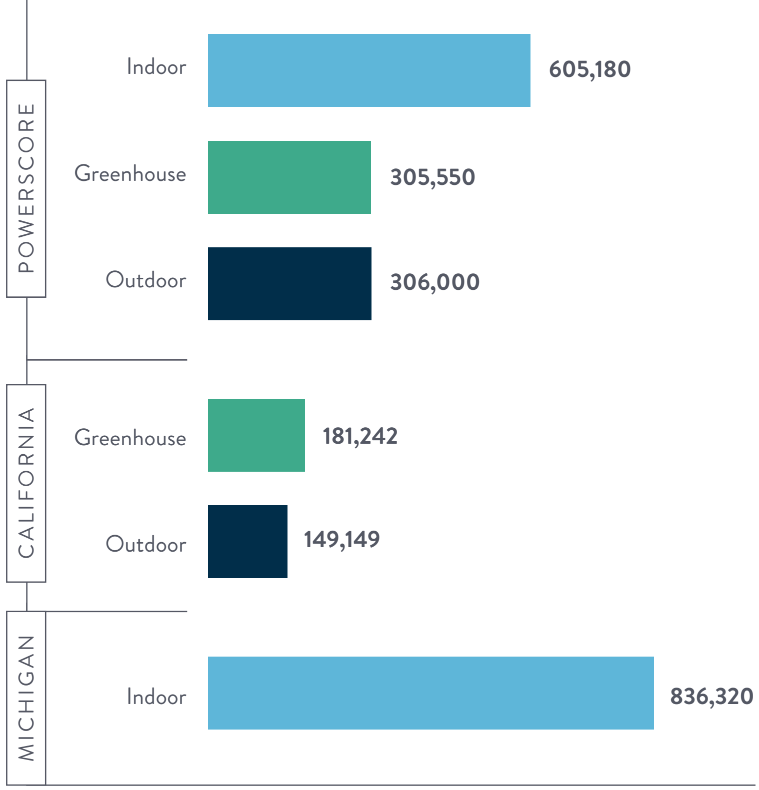
The Northern California Data Set and the Michigan Data Set describe only application water; California dataset does not distinguish water storage demand from water application demand, and instead distinguishes applied water demand that is served directly by water sources and demand served by stored water.

Facility Water Demand (gallons/year)

Facilities in the PowerScore Ranked Water Data Set show average annual water usage of 605,180; 305,550; and 306,000 gallons per year for indoor, mixed-light, and outdoor cultivation operations, respectively.

Facilities in the Northern California 2019 Data Set show average annual water usage of 181,242 and 149,149 gallons per year for mixed-light and outdoor cultivation operations, respectively.

FIGURE 23: Average Annual Water Use
Gallons/Year



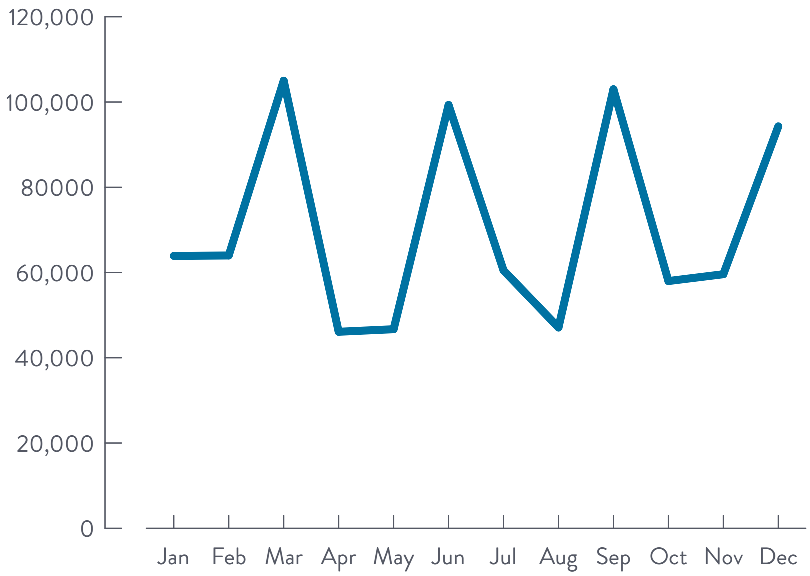
Indoor facilities in the Michigan 2020 Data Set show average annual water usage of 836,320 gallons per year.

Facility Water Demand (gallons/month)

Indoor facilities in the PowerScore Ranked Water Data Set show average monthly water application rates of 69,200 to 124,000 gallons per month, with peaks in each of March, June, September, and December. There are three months between each peak, which coincides with the interval between harvest cycles of mature cannabis (three-month plant lifespan). Some reasons why cyclical peaks emerge in the small data set of 23 records may include:

FIGURE 24: PowerScore Average Monthly Water Use

Gallons Applied per Month



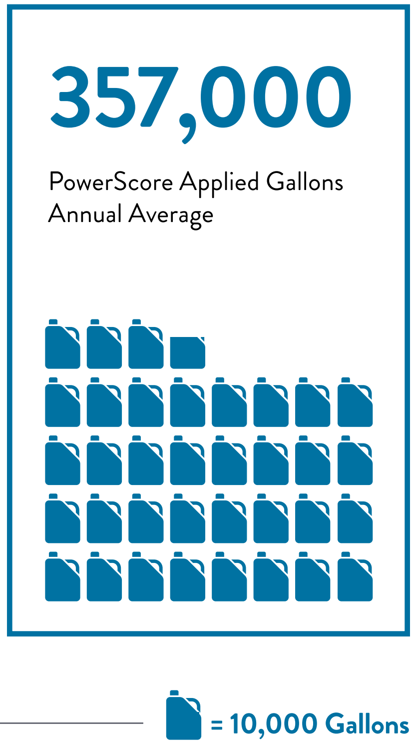
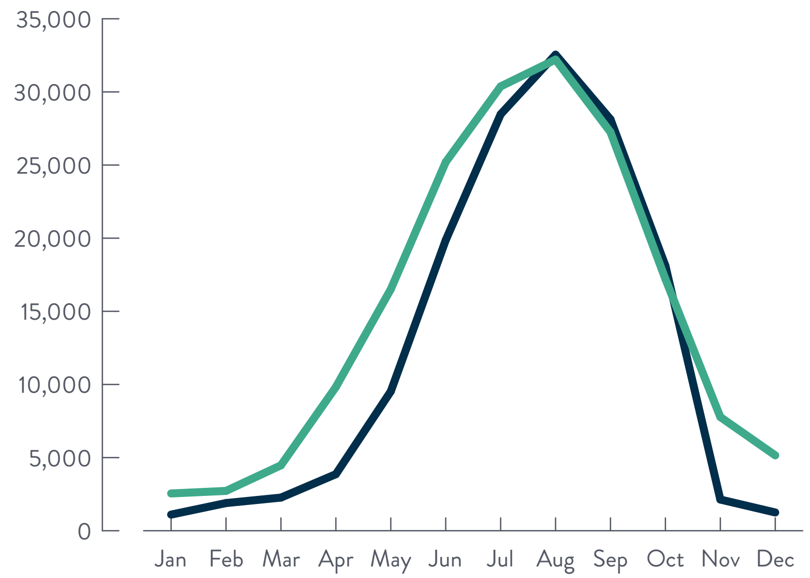


FIGURE 25: California Average Monthly Water Use

Gallons Applied per Month



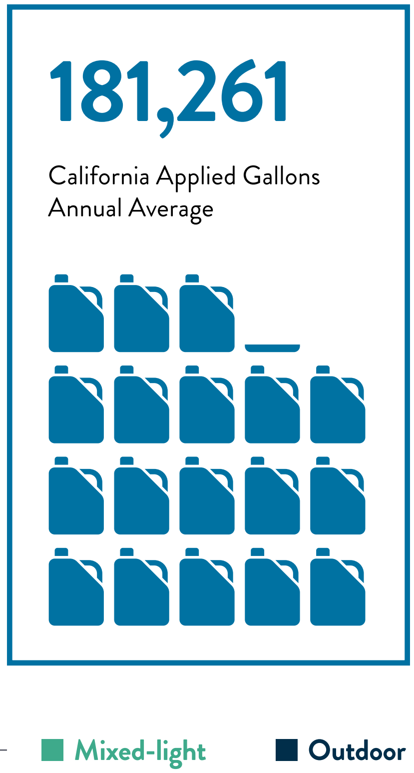
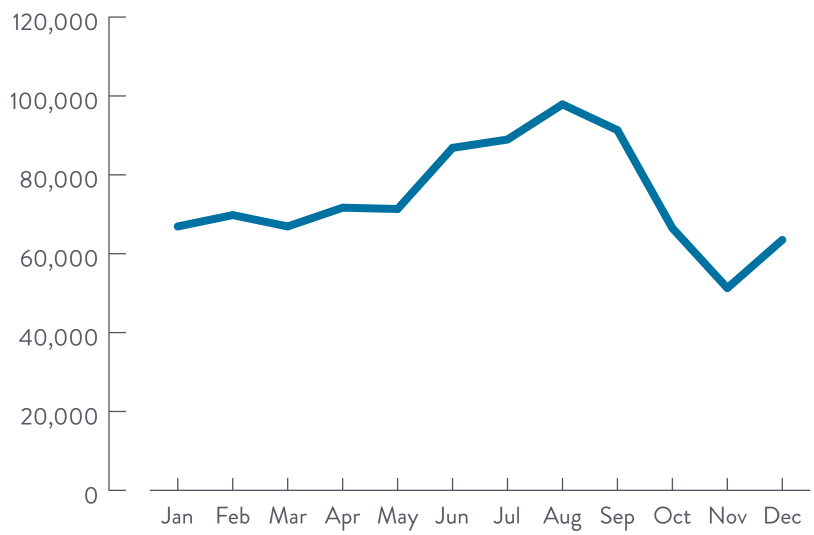
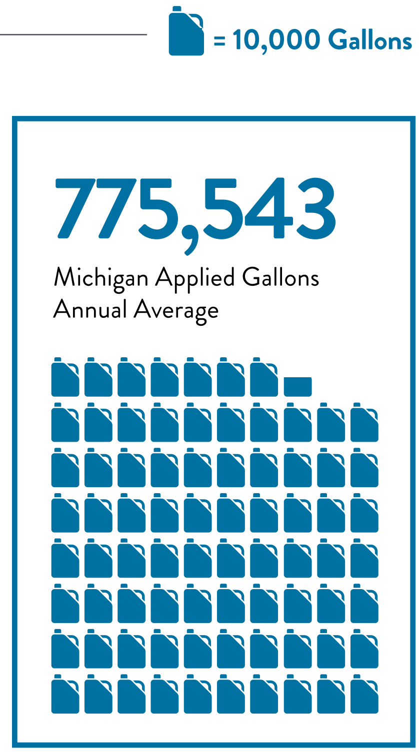


FIGURE 26: Michigan Average Monthly Applied Gallons





- The cultivators are predominantly single harvests at one time, instead of perpetual harvests throughout the year;
- Legalization schedules may take effect at the beginning of a calendar year; or
- Christmas and summer representing the biggest months for demand, so cultivators may sync with sales demand

Greenhouse operations in the Northern California Data Set show average monthly water application rates of 2,547 to 32,211 gallons per month, with peaks from June to September. Outdoor farms in the Northern California Data Set show average monthly water application rates of 1,102 to 32,546 gallons per month, with June to September also representing a peak period.

Some reasons why cyclical peaks may emerge in the data set include:

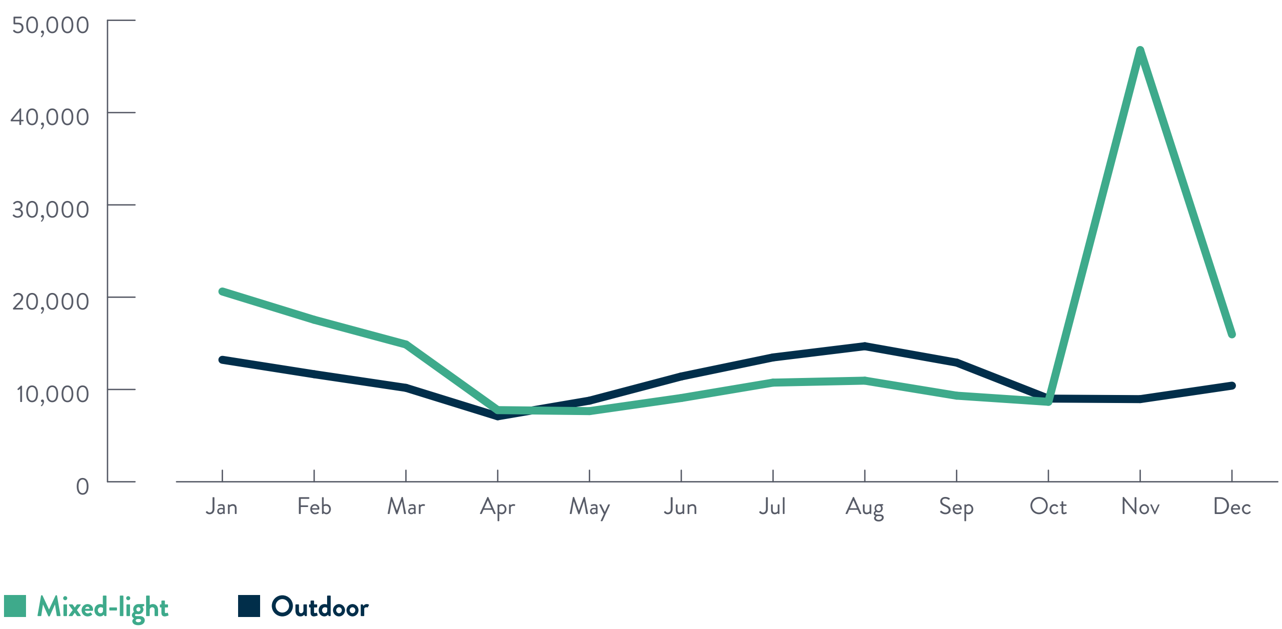
- Facilities cultivating sun-grown cannabis, and those using supplemental light, are affected by seasonal changes in photoperiod and intensity of solar radiation; and
- June through September is the warmest period among California's seasons.

Indoor facilities in Michigan show average monthly water application rates of 47,100 to 105,000 gallons per month, with peaks in June to September. Compared to the PowerScore Ranked Water Data Set facilities, Michigan facilities have lower peak water application rates.

- Some reasons why cyclical peaks do not emerge in this small data set of 12 records may include:
- Some cultivators getting started in their first year of operations, with data not yet representing fully typical water application rates.

FIGURE 27: California Average Monthly Water Storage

Gallons Stored per Month



Average Water Stored by Facility Type

Gallons Stored by Month

Month	Mixed-light	Outdoor
January	20,615	13,214
February	17,552	11,652
March	14,876	10,176
April	7,762	7,094
May	7,654	8,788
June	9,075	11,409
July	10,742	13,471
August	10,954	14,686
September	9,328	12,913
October	8,663	9,010
November	46,774	8,953
December	15,968	10,412

Water Storage Rates (gallons/year & gallons/month)

Mixed-light facilities in the Northern California Data Set show average monthly water storage rates (i.e., average amount of water stored on-site each month) of 7,654 to 46,774 gallons per month, with peak storage in November. Outdoor farms in the Northern California Data Set show average monthly water storage rates of 7,094 to 14,686 gallons per month, with peak storage in August. Input to storage from surface water or springs is generally prohibited from March to November in Northern California. Therefore, most input to storage from April to October likely comes from wells, and is most likely not long-term storage.

total industry
Water Consumption

U.S Cannabis Industry Size & Demand Outlook

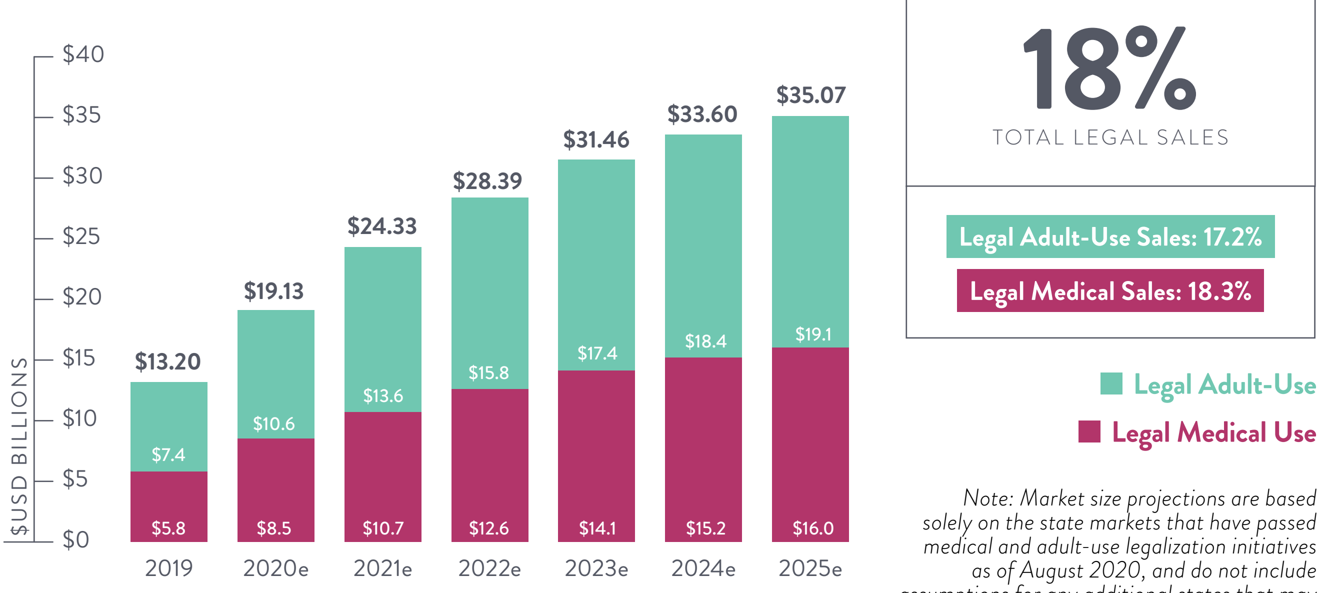
U.S. Cannabis Industry Growth & Market Outlook

The U.S. cannabis industry is experiencing surging growth, driven both by continued expansion of legal markets and rising consumer demand. With the market growing at a compound annual growth rate of 18%, legal market sales in 2020 are estimated at $19.1 billion, rising to over $35 billion by 2025. However, despite the legal market's growth, the illicit market continues to be the primary source for the majority of cannabis consumers, generating $67 billion in sales in 2020 alone.

Collectively, total U.S. consumer spending on cannabis totaled $86 billion in 2020, and is forecast to grow to over $105 billion by 2025.

The growth in revenue is fueled by rising rates of cannabis use in the U.S. According to the National Survey on Drug Use and Health, the prevalence of past-month cannabis use among adults aged 18+ increased 50% between 2010 and 2018, from 6.8% to 9.5%. By 2025, the prevalence of adult cannabis use is forecast to reach 12.5%, an 85% increase from 2010.

FIGURE 28: Growth of the U.S. Legal Cannabis Industry
2019-2025 est. ($USD billions)



Note: Market size projections are based solely on the state markets that have passed medical and adult-use legalization initiatives as of August 2020, and do not include assumptions for any additional states that may pass legalization measures in the future.

The legal market's growth is driven by the growing number of states that have passed medical or adult-use measures. In 2020, four states (Arizona, Montana, New Jersey, and South Dakota) passed adult-use measures, and two (Mississippi along with South Dakota, again) approved medical measures, increasing the number of adult-use states to 15, with 36 states legalizing medical use. While the forecasts account for only those states where cannabis is currently legal, large markets including New York, Florida, and Pennsylvania are all expected to pass adult- use measures in the next two years, while Texas and Southeastern states including Alabama, Georgia, and the Carolinas are expected to advance medical-use legalization.

KEY TRENDS DRIVING INCREASED DEMAND FOR CANNABIS

A convergence of market factors is driving increased demand for cannabis in the U.S.

SCIENTIFIC AFFIRMATION OF THE THERAPEUTIC APPLICATIONS FOR CANNABIS

There are over 60 medical conditions for which states permit patients to use medical cannabis, ranging from cancer and chronic pain, to glaucoma and multiple sclerosis. Further, some states including California and Oklahoma allow physicians to recommend cannabis for any condition for which the provider believes the patient might benefit.. With a large body of scientific research patient testimonials affirming medical cannabis, a growing proportion of the population are integrating cannabis into their treatment options.

DIVERSIFICATION OF CONSUMER PRODUCTS AND USE CASES

In the illicit market, smokable flower and concentrates, including vapes, are the most widely consumed product forms. However, in legal markets, well-capitalized companies have been able to develop increasingly elegant value-added products ranging from infused edibles and beverages, to cosmetics, suppositories, and feminine care products. These noncombustible products create new use cases for cannabis, enabling consumers to integrate cannabis into their lives in novel ways. While flower remains the most popular product among legal markets, over the past six years its share of sales has fallen from over 90% to approximately 50% in mature adult-use markets like Colorado. The trend is expected to accelerate as more states legalize, and as consumers across the country are more exposed to the value-added product segment.

SHIFTING SOCIAL ATTITUDES.

Public attitudes around cannabis have shifted dramatically in recent years. Fully two-thirds of Americans now support full legalization, and (per a 2020 Gallup study) 70% of Americans view smoking cannabis as morally acceptable. The erosion of cannabis stigma has resulted in its being consumed in many more social settings than where it was considered acceptable even a few years ago, providing infrequent consumers with more use occasions while displacing some alcohol sales. Displacement of alcohol sales by cannabis is expected to be a durable long-term trend, especially among younger consumers maturing in environments where cannabis is increasingly viewed as equally acceptable, legal, or safer than alcohol.

National Water Use In Cannabis Cultivation

Estimating Total Production Volume

To estimate the total water used in U.S.cannabis cultivation, the first step was to determine the quantity of cannabis produced to serve U.S. demand. Using production data from Colorado (which shows how much cannabis was produced to serve the retail demand), we developed a national estimate for cannabis flower production by facility type.

For 2020, we estimated that 34 million pounds of cannabis flower were produced to serve U.S. consumers across both legal and illicit markets, with a production forecast to rise to nearly 41 million pounds by 2025. The legal market accounted for approximately one-quarter (23%) of the market's supply.

FIGURE 29: Share of Market, Pounds Produced

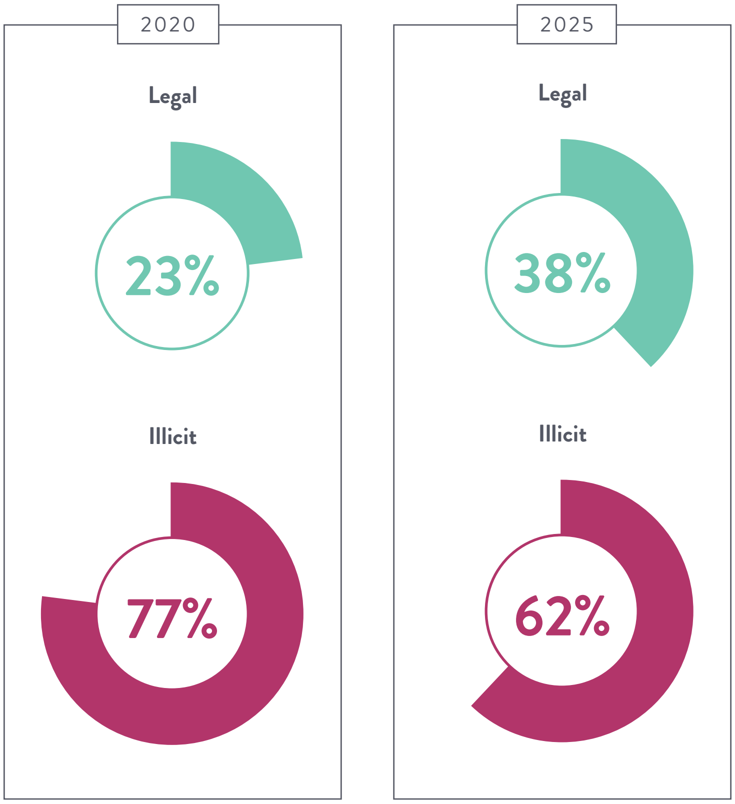
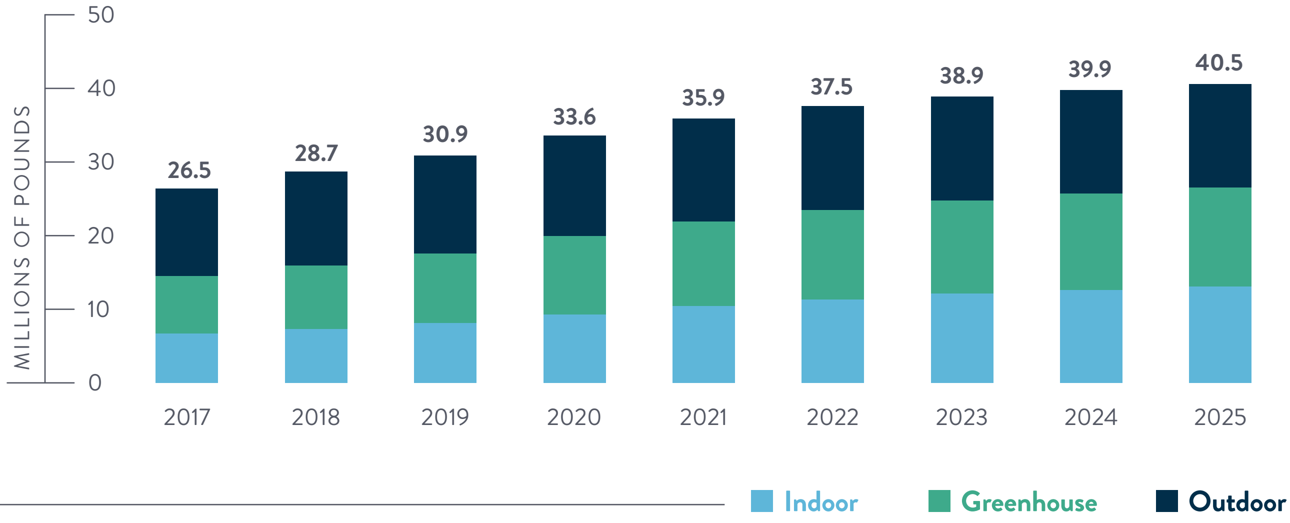


FIGURE 30: U.S. Total Cannabis Cultivation

by Facility Type, 2017-2025



LEGAL MARKET PRODUCTION

With the strong growth of the legal market, including the addition of five new legal states following the 2020 election, U.S. legal production is forecast to grow 102% between 2020 and 2025, from 7.7 million pounds to 15.6 million pounds. Since many of the newly legal states are in areas with suboptimal environmental conditions to produce cannabis outdoors, most of the growth in production will be in indoor and greenhouse/mixed-light facilities.

ILLICIT MARKET PRODUCTION

Outdoor production dominates the illicit market, accounting for nearly half (48%) of all production, in large part due to California's outsized share of cannabis sold across the U.S. Compared to the legal market, the illicit market is forecast to decline by 4% between 2020 and 2025, underscoring the increasing role that the legal market is playing is disrupting the illicit market.

Facility Size Estimates

Based on input provided by RII's Technical Advisory Council and Water Working Group, and consultation with other growers in the legal market on the average yields per square foot of flowering canopy, we developed high-, medium-, and low-range estimates for the amount of square footage required to meet the national production volume.

FIGURE 31: U.S. Legal Cannabis Cultivation
by Facility Type, 2017-2025

102% 2020-2025 Change

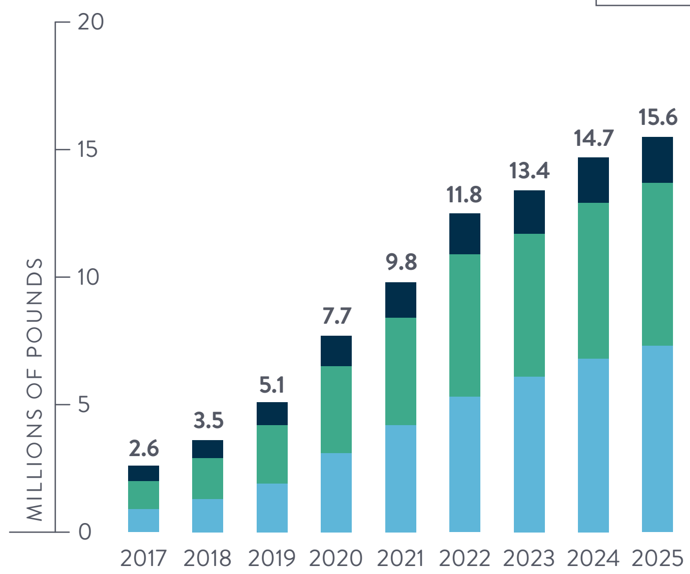


FIGURE 32: U.S. Illicit Cannabis Cultivation
by Facility Type, 2017-2025

-4% 2020-2025 Change

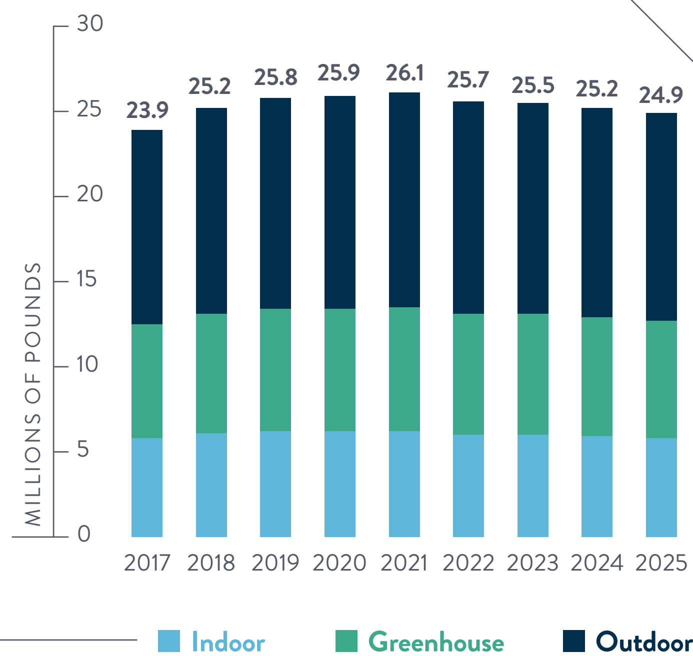


FIGURE 33: 2020 Share of Sq. Footage
Mid-Range Estimates

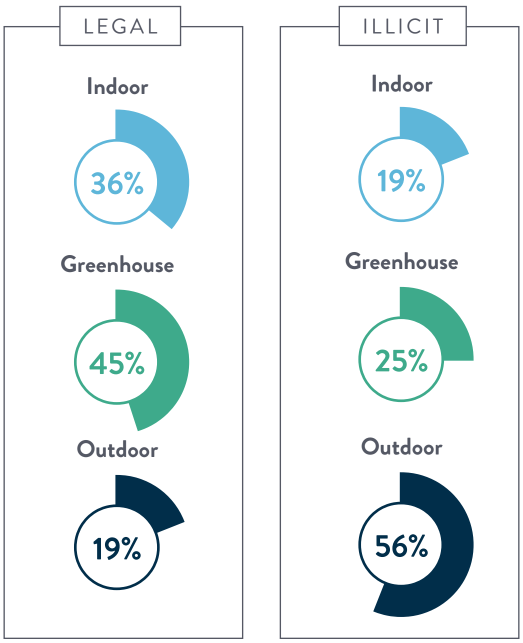
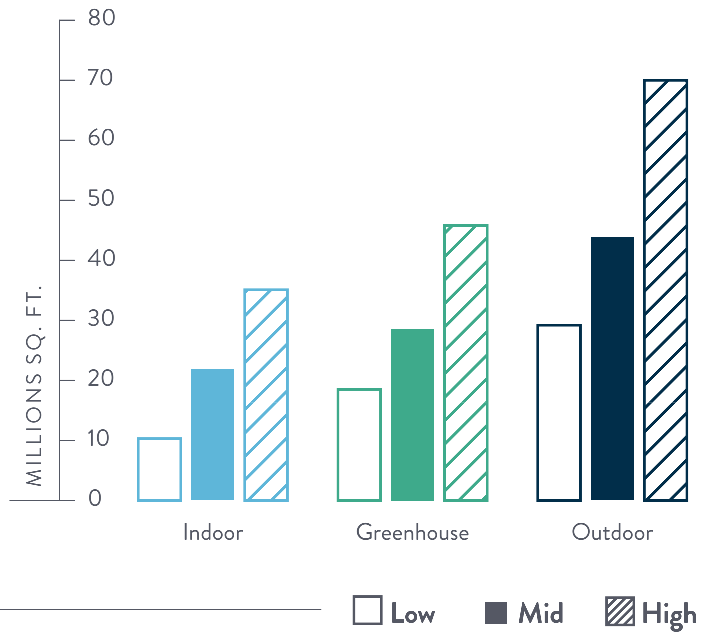


FIGURE 34: 2020 Cannabis Cultivation by Facility Type
Low/Mid/High Estimates



In 2020, the estimated square footage for indoor flowering canopy ranged from 10.3 million to 35 million square feet; greenhouse flowering canopy ranged from 18 million to 45 million square feet, and outdoor canopy ranged from 29 million to 70 million square feet.

Based on the mid-range estimate, 94 million square feet of flowering canopy was harvested in 2020, and is forecast to grow to nearly 112 million square feet by 2025.

Under the mid-range estimate, legal flowering canopy accounts for approximately one-fifth (36%) of the 112 million total square feet of flowering canopy in the U.S.

FIGURE 35: Total Sq. Footage Used to Grow Cannabis
Single Annual Harvest, Low/Mid/High Estimates

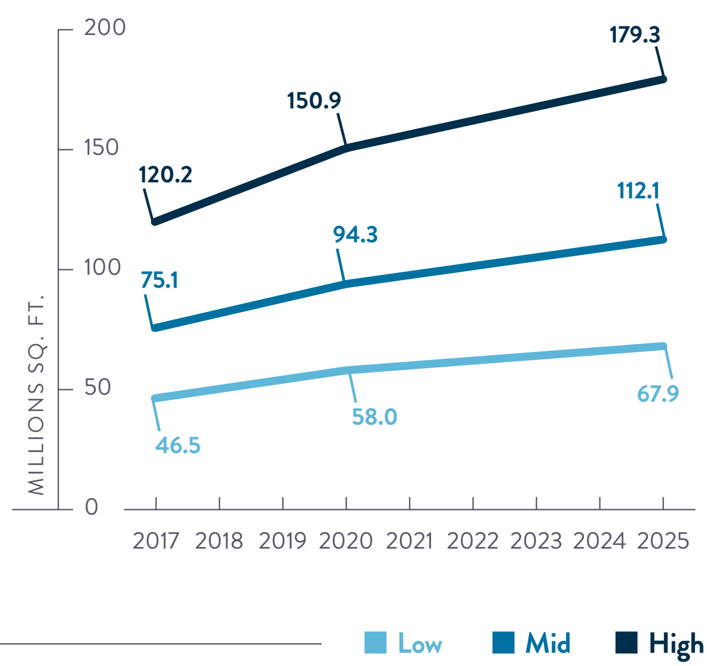
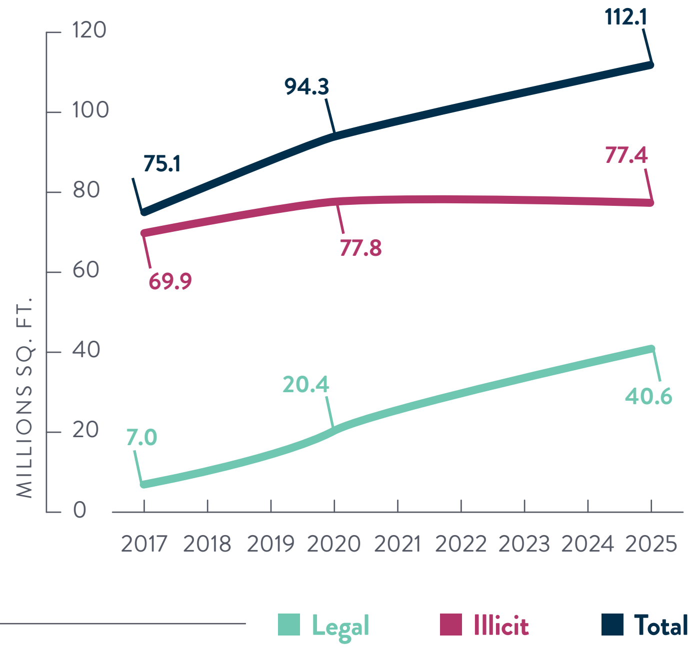


FIGURE 36: U.S. Cannabis Cultivation Total Sq. Footage
by Market, Mid-Range Estimates



Operational Flowering Canopy

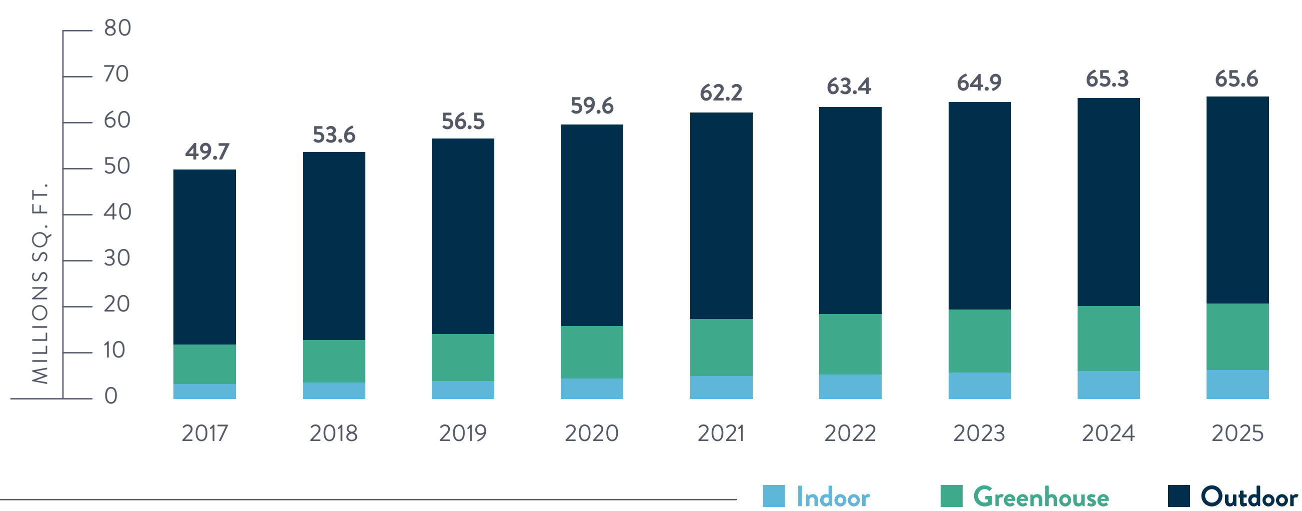
One of the challenges in measuring the operational square footage used to produce cannabis in the U.S. is the variance in the number of harvests per year within each type of facility. Typically, while outdoor growers only harvest once a year, greenhouse growers can harvest two or three times per year, and indoor growers can harvest five or more times per year.

Assuming the multiple harvests for indoor and greenhouse growers above, and a single harvest for outdoor growers, there was an estimated 60 million square feet of operational flowering square footage in 2020, growing to 66 million by 2025.

FIGURE 37: Typical Number of Harvests per Year

Indoor	Greenhouse *without Supplemental Light*	Greenhouse *with Supplemental Light*	Outdoor
5	3	2	1

FIGURE 38: U.S. Total Sq. Footage of Flowering Canopy



Water Usage

Data provided from Northern California established a baseline for applied water and storage capacity across cannabis cultivation operations. While the water use data in California may not be fully representative of operational practices elsewhere in the country, as the country's largest cannabis producer, the state's data offers valuable perspective on water use in the country's most consequential cannabis market.

Extrapolating the California usage data to the national market, we estimate that cannabis producers apply nearly 700 million gallons of water to their crops, and store nearly 850 million gallons of water for their operations.

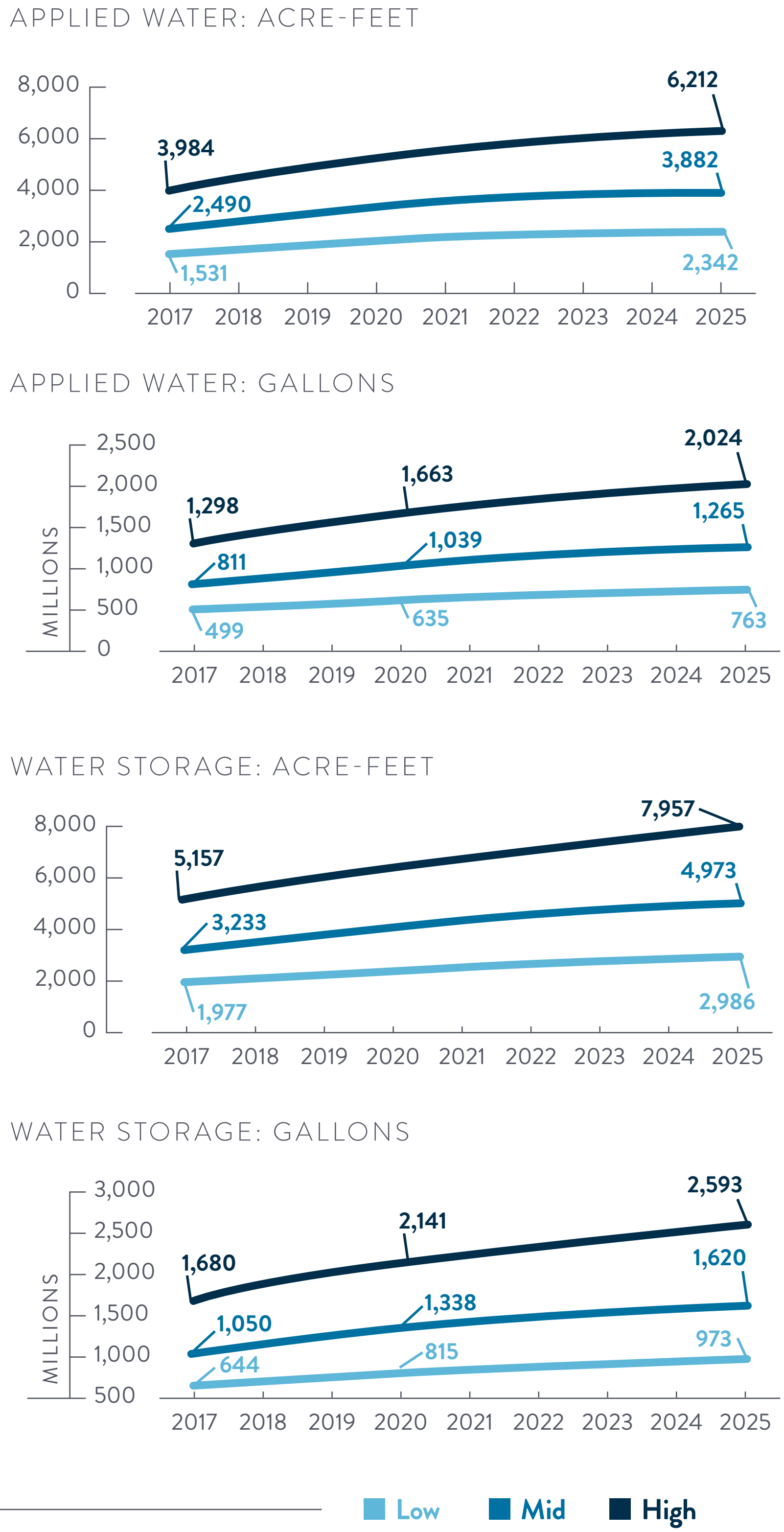
RII's PowerScore: Total Water Usage

The RII PowerScore data offers a more expansive view on the total volume of water used to cultivate cannabis. Extrapolating the acre-feet used per acre of flowering canopy yields an mid-range estimate of 8,595 acre-feet of water being used annually across the industry. Water use is forecast to rise to 11,065 acre-feet by 2025.

The illicit market will remain the primary driver of water use over the

FIGURE 39: Water Use in Cannabis Cultivation

Low/Mid/High Estimates



next five years, accounting for 83% of water use in 2020, and declining to 69% in 2025. However, water use in the legal market is expected to increase dramatically, rising 68% between 2020 and 2025 as the currently legal markets operationalize and build capacity to meet surging consumer demand.

The shifting economics of cannabis, with greater focus on efficiency and reducing resource use, will drive down production costs in the legal market, making it more competitive against the unregulated market.

FIGURE 40: Water Use in Cannabis Cultivation

Low/Mid/High Estimates

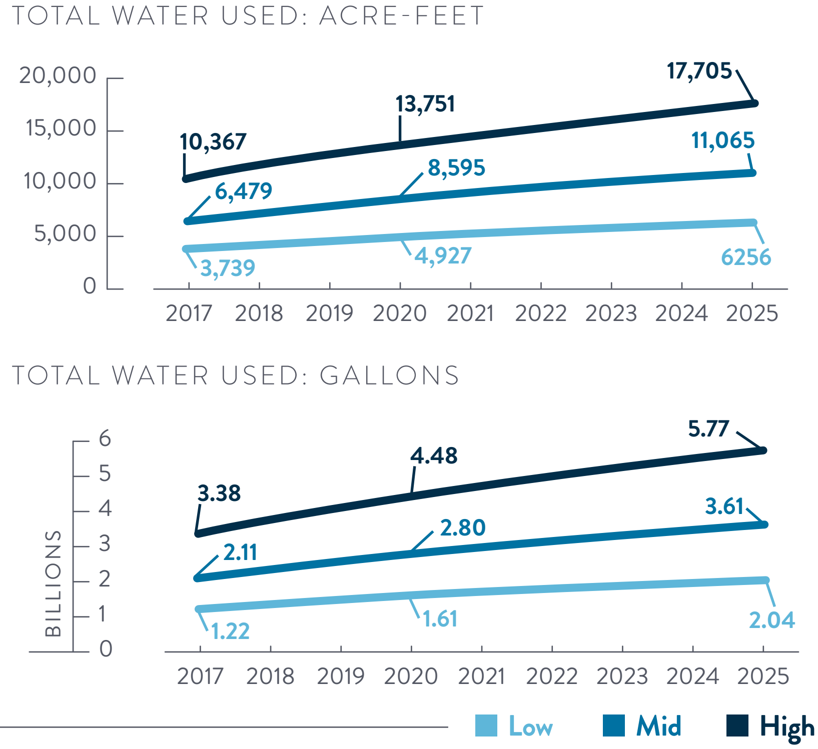


FIGURE 41: Water Use by Market Type

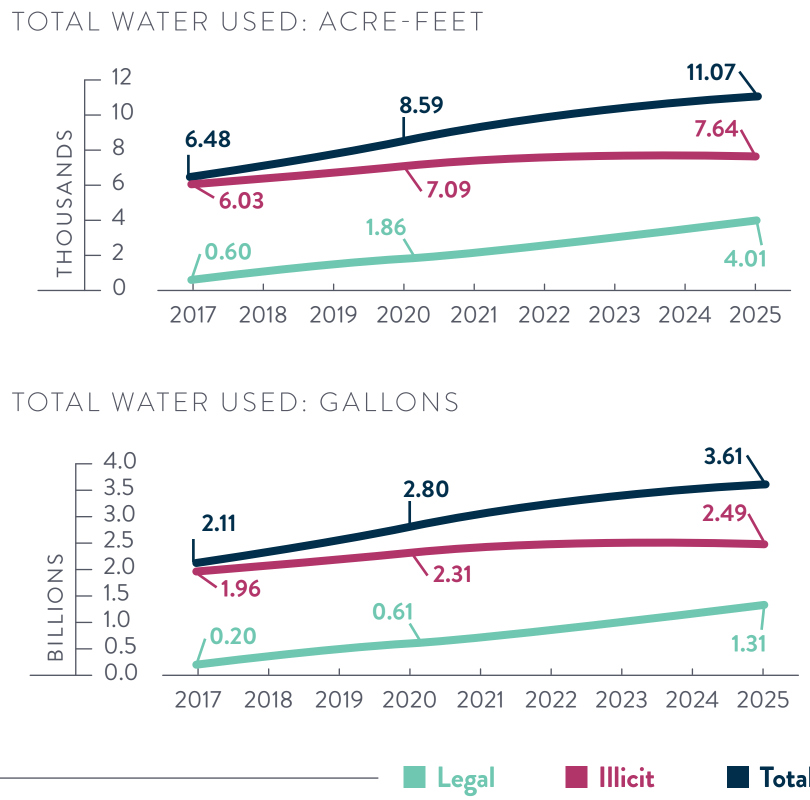
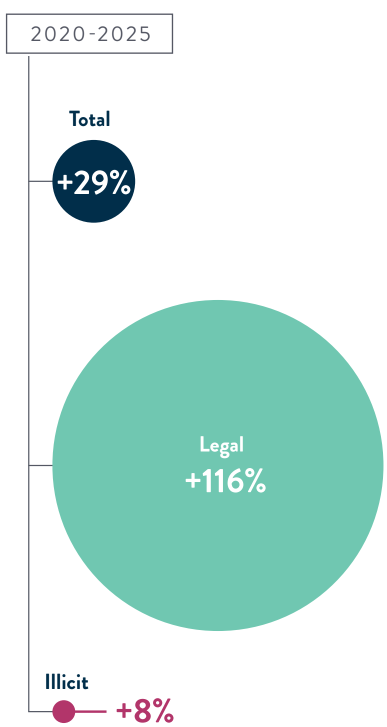


FIGURE 42:
Change in Total Water Use

by Market Type



Estimating Water Use Per Plant

Estimating the water used per cannabis plant is challenging, due to the wide variability in the number of plants grown per acre. Outdoor growers seeking to maximize the size of their plants may grow as few as 300 plants per acre, whereas indoor growers may choose a far more densely packed approach for thousands of plants per acre. The extremely high variability in plant size and length of cultivation cycle makes it impossible to create meaningful comparisons of water use per plant across different facilities with widely varied operational practices. Consequently, the wide ranges render meaningless any attempts to establish a per-plant benchmark, because plant density is so heavily dependent on the grower's preferred approach.

Equivalencies: Cannabis Cultivation Water Use in Context

At 2.23 billion gallons per year,
the water use in cannabis is equivalent to...

39.5 Million
American's Daily Water Use
A little more than the population of TX

Daily Industry Water Use in...

Livestock Farming:
2 Billion gal/day

Mining:
4 Billion gal/day

4,276
Olympic Size Swimming Pools

9,671
Coffee Shops Annual Water
Based on each shop using 800 gal/day
Equiv. to the number of Dunkin Donuts in the U.S.

6 Days
in U.S. Hotels
If every room was occupied
Assuming 100 gal/room/day

1.3 Days
on U.S. Golf Courses
Amount of water used to irrigate all U.S. golf courses

1 Hour
at Niagara Falls
62 minutes of water over the falls

1" of Rain
Over New Orleans
Equiv. to 1" of rain over 167 sq. mt.

Case Studies

Case Study #1

UNDERSTANDING THE ENVIRONMENTAL IMPORTANCE OF WATER STORAGE IN NORTHERN CALIFORNIA

The Medicinal and Adult-Use Cannabis Regulation and Safety Act (MAUCRSA) creates the general framework for the commercial regulation of medicinal and adult-use cannabis in California. A feature of the act is that it granted ability to the California Department of Fish and Wildlife and the state's Water Boards to provide the licensing authority with data showing that a watershed is significantly adversely impacted by cannabis cultivation. The licensing authority may then limit the number of plants or licenses within an impacted watershed. Elijah Portugal is a senior environmental scientist with the California Department of Fish and Wildlife, working with the cannabis and instream flow unit which assesses cannabis impacts on the environment, and helps to guide CDFW decision-making. Since the program's inception, Portugal and other CDFW scientists have been developing studies and protocols to monitor the interaction between cannabis water use and stream health. "Many of the watersheds where cannabis has historically been grown are important habitats for threatened or endangered salmon and steelhead trout" Portugal has noted. "Through a two-year pilot study conducted solely in the headwaters of the Upper Mattole River Watershed, we did not document a systematic trend of flow impairment due to cannabis, but we did document some flow impairment in one of our study streams. Specifically, we documented that water withdrawals, primarily for cannabis, reduced streamflows to a hazardous level ~ 2 weeks earlier during the baseflow period than would have occurred without any water use. Our monitoring and research efforts are focused on understanding the relationship between cannabis and the environment. We are especially concerned about watersheds that have experienced recent, unregulated growth in the cannabis industry, and also contain populations of salmon or other threatened or endangered species."

The need for such a program stems from the unique climate and geology of Northern California. "In Northern California, we have a Mediterranean-type climate where we typically don't get rain in the summertime. Even in the absence of any human water use, it's common for streams to be at base flow, or in the case of intermittent streams completely dry for much of the late summer," Portugal explained. "This is a time when Northern California streams are the most vulnerable to dewatering. The endangered salmonids and other aquatic and amphibian biota that require sufficient instream flow are going to be even more impacted than they already are, if cannabis cultivators are diverting during this period."

The regulated cultivator community is required to forbear from surface water diversions from April 1-October 31, but a large portion of cultivators in the state are not in the regulated market, and are likely diverting during the late summer period. Of additional concern to CDFW is the prevalence of late summer well use to meet cannabis water demand. Currently there are no requirements for well users to refrain from pumping groundwater for cannabis during the low flow period, but fundamental principles of hydrology and the primary literature reveal that groundwater and surface water are connected but – over extremely variable timescales. This means that, depending on the underlying lithology and proximity to the stream and characteristics of the well itself, much well use can have little to no impact on surface water, but in some cases it can impact surface water. The timing of low streamflow presents an issue generally for cannabis diverters, because the months that have the lowest natural stream flows are also the months that require the most irrigation for cannabis. Cannabis farmers need to irrigate the most during this time period, so there is potential for competition and conflict.

One important way to potentially mitigate conflict is through water storage. "Storage is really critical from our perspective," Portugal notes. "Essentially, if a cultivator has enough storage through permitted off-stream ponds, water tanks, bladders or other means, they are able to irrigate in the summer without reducing base flows." That is because the Northern California region receives plenty of rain in the winter, and farmers therefore can either store water directly from rain or pump water from streams in the winter, when water is more abundant.

"Farmers can take flow during the wetter winter months, and use that to meet late summer water demand," Portugal explains. "That really is the best way that farmers can minimize or eliminate streamflow impacts. If they're not extracting water from the watershed during its most vulnerable period, that's great, and that's supported by CDFW."

Case Study #2

GETTING BACK TO BASICS

In nine seasons working at Humboldt Nation Farms, Dave Stanley had a firsthand view of massive changes impacting the cannabis industry. Now the operations manager, Stanley's tenure includes the farm's maturation during California's medicinal and recreational rollouts. While the farm has strictly adopted California's stringent licensing requirements, including handicapped-accessible parking and building codes, the farm itself has not greatly changed since Proposition 64 in 2016.

Stanley said the farm cultivates about 7,200 square feet of canopy, which at any time holds between 1,200 to 1,600 plants. The plants are grown in raised beds primarily composed of soils nourished over 15 to 20 years. The farm is terraced, with sufficient water resources from a 500,000-gallon, rain-fed pond.

"We have always emphasized caring for the soil, and believe that we can make the farm better all the time," Stanley said. He has adopted a back-to-basics watering approach over the past few seasons. "We had trouble with our drip irrigation system, primarily because of the terraced nature of the farm. With my assistant, we now water every plant by hand, usually every other day."

Watering 1,400 plants by hand is neither quick nor easy. "I start at the top, and my partner starts at the bottom of the terraces," Stanley said. "It takes us about two hours to complete the job." To facilitate the watering technique, plants are planted in small, dug-out bowls in the soil. "We then flood the bowl each time we water, basically flood-irrigating every plant individually."On average, that means a five-second squirt for each plant, equal to about a half-gallon.

While the growing techniques have not radically altered due to regulations, there have been a few unexpected changes. First, water use is now closely measured and recorded. "In the old days, the theory was not to write anything down. Now, we can record our water use and other data. This allows us to improve our farm," Stanley said. Another unintended consequence has to do with the use of hay mulch. For years, Humboldt Nation had used hay mulch to help conserve water. Yet, it is difficult to obtain organic hay. "If we used hay that happened to have any pesticide residue on it, it could get into our plants and we could fail a test," Stanley said, adding that "it is just not worth the risk." Subsequently, Humboldt Nation no longer uses any mulch, and Stanley suspects that the hard crust that forms after watering effectively prevents water from evaporating.

While watering by hand is time-consuming, it offers many benefits. "We always have plants at the end of the rows that get more sunlight; by hand-watering, we are able to make sure these plants get just a bit more water." Beyond precision water application, there are other, larger benefits. "Because we are watering by hand, we see every plant, at least every other day," Stanley said. "This allows us to really observe our plants, and catch problems early on."

Key Takeaways
& Strategic Recommendations

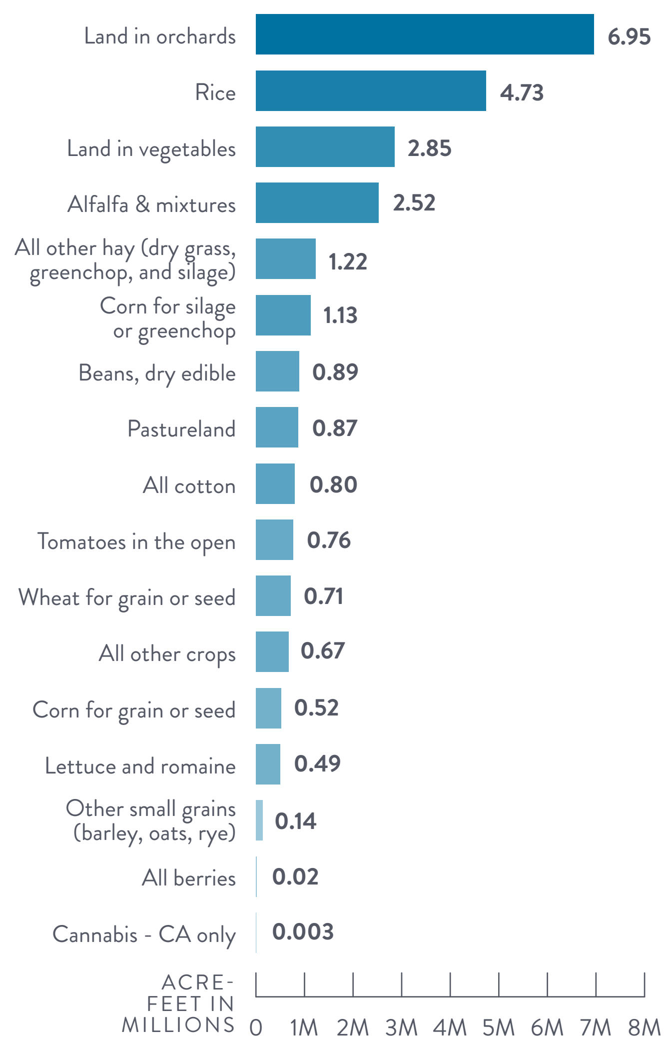
Cannabis is Not a Major Contributor to Water Use in U.S. Agriculture

As states like California have faced increasingly acute water shortages, the fast-growing cannabis industry has often been blamed for drawing down the state's water supply. That assessment is often based on an incorrect correlation between large revenues earned by the cannabis industry and production levels seen in other high-revenue cash crops. However, whereas wholesale pounds of cotton, rice, and table grapes may sell for about$0.60, $0.71, and $0.78, respectively, a wholesale pound of smokable cannabis bud can fetch $1,500 to $3,000 or more, depending on the quality. Consequently, the market value for the cannabis industry grows dramatically, even with only incremental increases in production.

Furthermore, relative to other major crops, cannabis requires significantly lower production volumes to meet consumer demand. For example, approximately 2.5 pounds (40 ounces) of grapes are required to produce a bottle of wine; by comparison, 40 ounces of smokable bud is over 3x more cannabis than

FIGURE 43: Water Use in California's Top Agricultural Crops*

Total Acre-Feet Applied



** Water use estimates for non-cannabis use crops are from 2013. Cannabis water use estimates are from 2020.*

Source: Johnson, R., Cody, B., California Agricultural Production and Irrigated Water Use, Congressional Research Service, June 30, 2015, New Frontier Data a frequent consumer would use in a calendar year. The low-volume nature of cannabis means that even as the industry grows it will continue to have limited impact on the overall use of water in California or across the country.

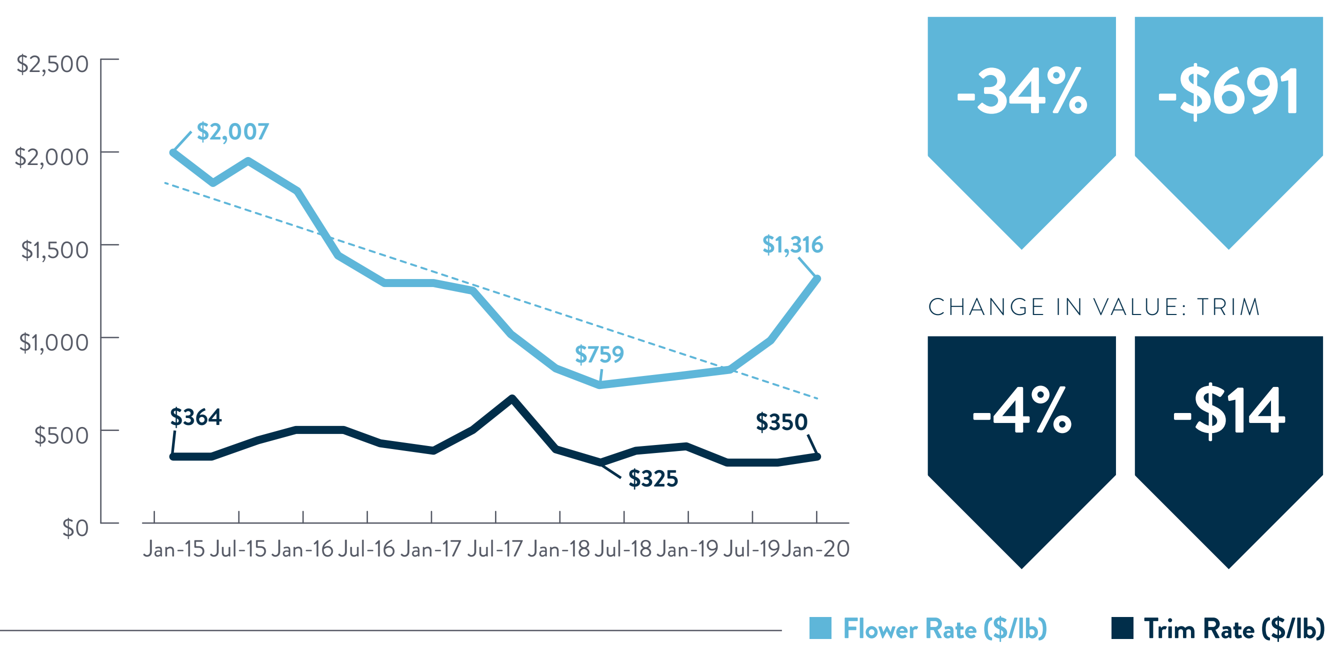
This analysis demonstrates that the volume of water used to grow cannabis is poised to increase significantly as demand for cannabis (especially in the legal market) surges. However, compared to typical major crops in the U.S. agricultural economy, the cannabis industry has a nominal impact on water used for farming. The impact of the industry's water use may be more pronounced in the drought-prone areas in the Western states. However, even in California and Oregon – two of the country's largest cannabis production markets – the volume of water use is dwarfed by other crops (e.g., fruit trees, grapes, corn, cotton, and rice). The industry is well positioned to improve the efficiency of water use as best practices become better known and water-efficiency solutions become more widely adopted. However, those gains will have greater impact on the bottom line for producers than against the national agricultural water supply.

A Competitive Cannabis Market Demands Water Efficiency

Surging Popularity of Value Added Products is Driving Increased Demand for Cannabis Biomass

Cannabis, the plant, can be grown to produce varying types of biomass. The 2018 Farm Act removed hemp (defined as cannabis with <0.3% THC) from the federal Schedule 1 controlled substances list, making it an ordinary agricultural commodity. Cannabis is grown to produce a few different industrial and

FIGURE 44: Average Market Rate for Cannabis Flower & Trim in Colorado
Jan 2015 - Oct 2020



agricultural products: fiber, seed, and flower. Flower can be harvested to be delivered to customers directly as smokable products, or can be refined further to be manufactured into value-added products.

The share of flower sales has fallen dramatically as the popularity of value-added products has surged, expanding the volume of cannabis biomass that must be produced to meet the production requirements for several new product categories.

Nationally, the share of flower across markets varies widely, influenced by the maturity of the market, regulations governing the sale of flower and other value-added options, and the structure of the operators in each market (i.e., in vertically integrated markets, non-flower products tend to emerge more slowly than in markets where individual licenses can be obtained for each point in the supply chain).

> Over time, value-added products will ultimately account for half or more of all product sales.

Generally, however, the trend toward a highly diversified product environment is consistent across all markets, with flower remaining the leading category, but over time value-added products will ultimately account for half or more of all product sales.

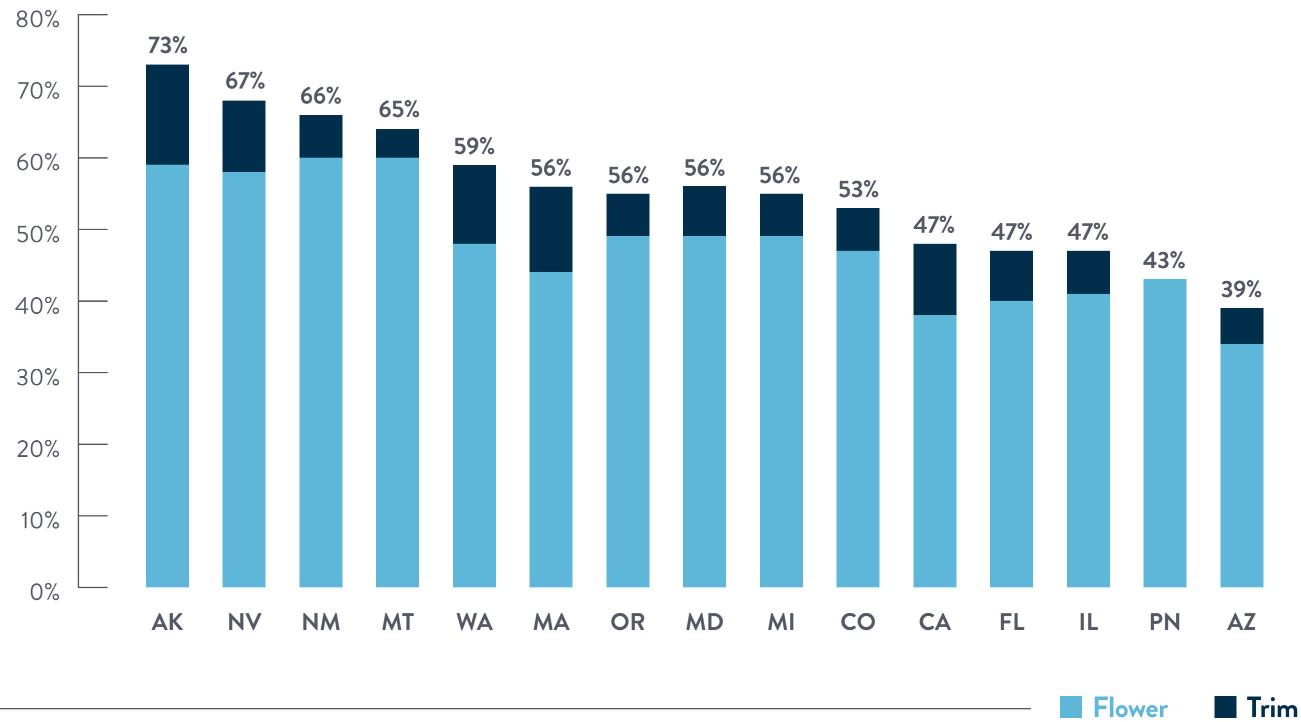
The Shifting Economics of Cannabis Underscores the Imperative for Operational Efficiency

The wholesale price of cannabis has been on a steady downward trajectory, driven by increased competition in the legal market as the number of licensed producers has risen, and greater efficiencies and economies and scale. Since 2015, the average price per pound in Colorado has fallen by one-third (34%), with the prices recovering significantly following a 61% decline to less than $800 per pound in the fall of 2018.

In the early period of high wholesale prices, low competition, and abundant resources, growers have little incentive to invest heavily in optimizing their efficiency but the speed at which market conditions shifted left inefficient operators unprepared to compete. Some companies, however, have recognized early the utility of maximizing efficiency early. In Oregon, Eco Firma Firms was a notable example, as the company brought its production cost per pound below $200/lb when many in the state were producing at two to four times that cost, and the company was able to continue to enjoy comfortable margins even as the average wholesale price per pound fell below $750.

Across the most mature markets, growers who have been unable to compete when prices were at their lowest were forced to sell or close their businesses. The loss of less efficient operators has eased some competition and allowed prices to rebound. However, with the market's continued evolution, including the continued evolution of consumer demand, the accelerating fragmentation

FIGURE 45: Flower & Pre-Roll Share of Sales in Select States
Oct 2020



of the consumer product environment, and the prospect of federal legalization over the next few years, growers must continue to work to maximize returns by prioritizing efficiency across their operators.

Not only will the most efficient growers be able to compete most effectively, they will be best positioned to secure investment capital, and will be the most attractive targets for acquisition as the industry consolidates and builds national and international scale.

To address the need for more data, governments should consider requiring producers to report their annual usage, as some U.S. states have done. Cannabis is in a unique position relative to other agricultural markets, as the legal market to serve most of the future demand remains very nascent. For now, governments and industry regulators have a shared opportunity to establish data collection and benchmarking processes to support the industry's future growth while the industry is in urgent need of performance metrics to inform industry-wide performance improvements. Governments should work with licensed operators to develop reporting protocols for resource use; while burdensome for growers to comply with, such protocols can provide a feedback mechanism to let them compare their performances against their peers', and make it easier to identify and share best practices among the industry's leaders. Resources such as Resource Innovation Institute's PowerScore tool offer a ready-made solution for secure deployment to collect high-value data for both regulators and operators.

The cannabis industry is primed for breakthrough advances in water efficiency, but significant research and knowledge-sharing will be required to capture and disseminate best practices. Governments, industry stakeholders, and others (e.g., philanthropic environmental foundations) should consider funding research and education about best practices for water efficiency. Lack of understanding about how growers can optimize their water use has led to too many inefficient practices being adopted from the unregulated market. However, with hundreds of new cannabis cultivation operations now positioned to come online in coming years as more states legalize medical and adult use, the value of investing in such knowledge-sharing can pay major dividends if done while the industry is at its infancy, before major investments are dedicated to new operations.

Analysis of water practices should not be performed on a "per plant" basis, and instead should consider a more thorough assessment of productivity, efficiency, demand, storage, and consumption. Growers use widely varied plant-management practices, making it extremely difficult to established normalized metrics for water use on a per-plant basis. While per-plant comparisons may be of value when comparing similar facilities with identical cultivation practices, using performance metrics that are pegged against size, yields, and total demand enables more effective comparative benchmarking industry-wide.

The industry should strongly encourage establishment of data-driven voluntary standards and recognition of top performers. In the emerging, quickly evolving market of legal cannabis, regulations can lag behind significant market developments. As such, waiting for government mandates about sustainability standards or dissemination of industry best practices will result in needlessly lost opportunities at a key period in the industry's growth. Industry trade groups at state and national levels should work aggressively to incorporate sustainability benchmarking and knowledge-sharing, and recognize those achieving the greatest improvements in efficiency.

Water impacts beyond direct runoff and discharge should also be evaluated. Other agricultural sectors are beginning to examine impacts from cultivation operations such as transportation, whereby fragments of vehicle tires have been found to cause fish die-off, and the cost of vehicular water transportation contributes to the industry's carbon footprint for water use. Similarly, though the widespread use of energy-intensive reverse osmosis may allow growers to reclaim and reuse water, it adds to overall production costs and resource inefficiencies due to those high energy requirements. As the industry works to develop resource-use metrics, operators and resource-management stakeholders should think expansively (and creatively) about how best to measure the total impact of all the inputs used to produce cannabis, and to measure the most efficient approaches based on the increasingly diverse solutions available to the market.

Conclusion

AS THE CANNABIS INDUSTRY matures, water use efficiency will become more important, as it has for other agricultural crops. Pressures to use water efficiently will mount from multiple channels including - reducing input and energy cost, protecting the environment, meeting regulatory standards and simply being good stewards.

We recommend that industry and regulators focus efforts on the following areas:

1. When grown outdoors, water for cannabis production should be assessed like any other agricultural crop and be subject to state and local regulations that apply to other crops. Our research indicates that cannabis neither uses a massive share of water or uses more water than other agricultural crops. Applying the same standards to cannabis as to other agricultural crops will correctly categorize outdoor grown cannabis as an agricultural crop.

2. In areas where there may be conflict between water use for cannabis and environmental concerns, regulators and the industry should focus (1) on the timing of water use and (2) the potential of storage to mitigate environmental conflict. Our results show that in many parts of the country legal cannabis farmers have ample water storage to satisfy their needs. In areas where storage is insufficient, increasing storage should be a priority for farmers and regulators.

3. Our research shows there are still massive differences between cannabis production techniques and to some extent this variation also is seen in our water use data. None-the-less, water efficiency is not the most important metric for most cannabis farmers. As farmers continue to experiment and improve, we expect to see water use be a more important part of cannabis farming decisions and expect new plant varieties and growing techniques to be developed that increase water use efficiency.

4. As indoor production continues to grow, especially in areas that have unfavorable climatic conditions for outdoor growing, we expect more cannabis users to rely on municipal water sources. Yet, it is unclear if municipal water suppliers are equipped to work with the cannabis industry. We suggest outreach efforts between the cannabis industry and municipal water suppliers to incentivise efficiency where possible.

Glossary

ACRE-FOOT: The acre-foot is a non-SI (i.e., International System of Units) unit of volume commonly used in reference to large-scale water resources, such as reservoirs, aqueducts, canals, sewer flow capacity, irrigation water, and river flows. An acre-foot equals approximately an eight-lane swimming pool (e.g., 82 feet long, by 52 feet wide, by 9.8 feet deep) OR a unit of volume equal to the volume of a sheet of water both one acre (0.405 hectare) in area and one foot (30.48 cm) in depth, i.e., 43,560 cubic feet (1,233.5 cubic meters).

AEROPONICS: The process of growing plants in an air or mist environment without the use of soil or an aggregate medium.

AQUAPONICS: Aquaponics refers to a food production system that couples aquaculture with hydroponics in a symbiotic environment whereby the nutrient-rich aquaculture water is fed to a hydroponically grown plant, involving nitrifying bacteria for converting ammonia into nitrates.

CATION: Positively charged ions. The essential soil cations are ammonium, calcium, magnesium, and potassium. They are critical for any plant to grow and flourish. Additional soil cations include sodium, aluminum, and hydrogen.

COCONUT (COCO) COIR: Coir, or coconut fiber, is a natural fiber extracted from the outer husk of coconut and used in products including floor mats, doormats, brushes, and mattresses. Coir is also the fibrous material found between the hard, internal shell and the outer coat of a coconut.

CONDENSATE: Water that accumulates as a result of condensation within a cultivation facility's heating, ventilation, and air-conditioning (HVAC) system.

DIATOMACEOUS EARTH: Diatomaceous earth consists of fossilized remains of diatoms, a type of hard-shelled protist. Diatomaceous earth has myriad industrial and horticultural applications, including non toxic pest control.

EVAPOTRANSPIRATION/TRANSPIRATION: Evapotranspiration is the sum of water evaporation and transpiration from a surface area to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies.

ELECTRICAL CONDUCTIVITY: The ability of water to conduct an electrical current; important because it can detect how much dissolved substances, chemicals, and minerals are present in the water. Higher amounts of the solutes will lead to a higher conductivity. While pure water has very low conductivity, sea water comes with much higher conductivity. Even a small amount of dissolved salts and chemicals can heighten the conductivity of water.

DELIVERED WATER: Water taken from a source and delivered to a user for either indoor or outdoor watering.

GREENHOUSE CULTIVATION: Greenhouse cultivation is the unique farm practice of growing crops within sheltered structures glazed with a transparent, or partially transparent, material like a hoop-house, glasshouse, conservatory, hothouse, or similar structure. The main purpose of a greenhouse is to use the sun to provide as much light energy for plants as possible, employing supplemental electric light as needed, and to protect crops from unfavorable weather and various pests.

HYDROPONICS: Hydroponics is a type of horticulture and a subset of hydroculture, which is a method of growing plants (usually crops) without soil by delivering nutrition and fertilizer via an aqueous solvent (e.g., water).

INDOOR CULTIVATION: Indoor cultivation is a farm practice of growing crops in sheltered structures with sole-source electric light. The main purpose of indoor cultivation is to control the growing environment more precisely to maintain optimal growing conditions and extend growing seasons.

LEACHATE: A leachate is any liquid that, in passing through matter, extracts either soluble or suspended solids, or any other component of the material through which it has passed.

LEACHATE PERCENTAGE: Volume of leachate divided by the volume of nutrient solution given to the crop.

LIVING SOIL: Living soil or no-till soil is a growing medium rich with organisms which function as their own ecosystem, breaking down organic and inorganic matter and providing nutrients to plants and other surrounding organisms. Often it is a soilless substrate, but with a highly variable mixture of different organic amendments.

OUTDOOR CULTIVATION: Outdoor cultivation is a traditional farm practice of growing crops in the ground without artificial lighting. Outdoor cultivation may allow for lower operating costs, but less control over the plant's growth cycle.

PERLITE: Perlite is a volcanic glass treated with heat to produce an especially lightweight material. In potting soil, perlite is a nonorganic additive used to aerate the substrate.

PH: Potential of hydrogen (pH) is a scale used to specify the acidity or basicity of an aqueous solution. Acidic solutions (i.e., solutions with higher concentrations of H^+ ions) are measured to have lower pH values than found in basic or alkaline solutions.

REVERSE OSMOSIS: A water-purification process that uses a partially permeable membrane to separate ions, unwanted molecules, and larger particles from drinking water.

ROCK WOOL: Rock wool is a lightweight, hydroponic substrate made from spinning molten basaltic rock into fine fibers formed into a range of cubes, blocks, growing slabs, and granular products. The product is chemically and biologically inert (i.e., ions are not bound or exchanged on substrate particle surfaces) and creates an ideal growing medium for hydroponic growing strategies.

POTABLE: Fresh water appropriate for human consumption, drawn from public drinking water supply systems or private wells.

MUNICIPAL POTABLE WATER: Water for public supply which has been determined to be fit or suitable for drinking.

NATURAL WATER SOURCE: Non-potable water occurring naturally (e.g., rainwater, surface water, or well water).

PRIVATE WELL / BORE: A private water source taken directly from the earth, e.g., when a hole is drilled to the aquifer for a pump system to deliver water to the surface.

NON-POTABLE: Not fit or suitable for drinking, but possibly of use for other purposes, depending on quality.

ON-SITE RECLAIMED (RECYCLED) WATER: Recycled water generally refers to treated domestic wastewater used more than once before passing back into the water cycle. The terms "reused" and "recycled" are often used interchangeably. . Reclaimed water is not reused or recycled until it is put to some purpose. It can be reclaimed and usable for a purpose, but not recycled until somebody uses it.

MIXED-LIGHT: Mixed-lighting refers to a lighting situation where both natural and artificial or supplemental lighting sources are utilized during the growth cycle.

PHYTOTOXIC: Toxic to plants.

SUBSTRATE: Substrate is the base on which cannabis plants grow. In agriculture, soil is the most common substrate. For cannabis, growers often use other media, including rock wool, coir, or peat.

SUPPLEMENTAL LIGHTING: Supplemental lighting, is often used in greenhouses, and refers to any additional quantity and quality of illumination not obtained by the general lighting system to support or increase crop production.

VERMICULITE: A group of hydrated laminar minerals. Horticultural vermiculite is processed with heat and expanded into pellets which can improve water and nutrient retention.

WATER DEMAND: A key benchmark in measuring water for cultivation, water demand is a measure of gallons applied per month or year.

WATER EFFICIENCY: A key benchmark in measuring water for cultivation, water efficiency is a measure of gallons applied per flowering canopy square feet.

WATER PRODUCTIVITY: A key benchmark in measuring water for cultivation, water productivity is a measure of gallons applied per gram of dry cannabis flower.

Appendix 1

U.S. Drought Monitor Classification Definitions

Category	Impact
D0	• *Soil is dry; irrigation begins early* • *Dryland crop germination is stunted* • *Active fire season begins* • *Winter resort visitation is low; snowpack is minimal*
D1	• *Dryland pasture growth is stunted; producers give supplemental feed to cattle* • *Landscaping and gardens need irrigation earlier, wildlife patterns begin to change* • *Stock ponds and creeks are lower than usual*
D2	• *Grazing land is inadequate* • *Producers increase water efficiency methods and drought-resistant crops* • *Fire season is longer, with high burn intensity, dry fuels, and large fire spatial extent; more fire crews are on staff* • *Wine country tourism increases, lake and river-based tourism declines; boat ramps close* • *Trees are stressed; plants increase reproductive mechanisms, wildlife diseases increase* • *Water temperature increases, programs to divert water to protect fish begin* • *River flows decrease; reservoir levels are low and banks are exposed*
D3	• *Livestock need expensive supplemental feed, cattle and horses are sold; little pasture remains, producers find it difficult to maintain organic meat requirements* • *Fruit trees bud early, producers begin irrigating in the winter* • *Federal water is not adequate to meet irrigation contracts; extracting supplemental groundwater is expensive* • *Dairy operations close* • *Marijuana growers illegally tap water out of rivers* • *Fire season lasts year-round; fires occur in typically wet parts of the state; burn bans are implemented* • *Ski and rafting business is low, mountain communities suffer* • *Orchard removal and well drilling company business increase; panning for gold increases* • *Low river levels impede fish migration and cause lower survival rates* • *Wildlife encroach on developed areas; little native food and water is available for bears, which hibernate less* • *Water sanitation is a concern, reservoir levels drop significantly, surface water is nearly dry, flows are very low; water theft occurs* • *Wells and aquifer levels decrease, homeowners drill new wells* • *Water conservation rebate programs increase, water use restrictions are implemented; water transfers increase* • *Water is inadequate for agriculture, wildlife, and urban needs; reservoirs are extremely low, hydropower is restricted*
D4	• *Field are left fallow; orchards are removed, vegetable yields are low; honey harvest is small* • *Fire season is very costly; number of fires and area burned are extensive* • *Many recreational activities are affected* • *Fish rescue and relocation begins; pine beetle infestation occurs; forest mortality is high; wetlands dry up; survival of native plants and animals is low; fewer wildflowers bloom; wildlife death is widespread; algae blooms appear* • *Policy change; agriculture unemployment is high, food aid is needed* • *Poor air quality affects health; greenhouse gas emissions increase as hydropower production decreases; West Nile Virus outbreaks rise* • *Water shortages are widespread; surface water is depleted; federal irrigation water deliveries are extremely low, junior water rights are curtailed; water prices are extremely high; wells are dry, more and deeper wells are drilled; water quality is poor*

Source: United States Drought Monitor

Appendix 2

Imperial to Metric Conversion

Imperial		Metric	
1	Gallons	**3.79**	Liters
1	Gallons/Sq. Ft.	**4.07**	Centimeter
1	Square Feet	**0.09**	Square Meters
1	Acres	**4046.86**	Square Meters
1	Acrefoot	**1233.48**	Cubic Meter
1	Ounce	**28.35**	Gram
1	Pound	**452.60**	Gram

Appendix 3

Acceptable Ranges for Chemical Properties in Irrigation Water

Chemical Property	Acceptable Range for Most Container-Grown Woody Crop	Acceptable Range for Most Container-Grown Herbaceous Perennials/ Greenhouse Crops	Acceptable Irrigation Purposes in a Greenhouse Using Soilless Substrates (Rockwool, Oasis, Peat or Coir)
pH	5.0-7.0	5.0-7.0	5.0-7.0
EC *(electrical conductivity - a measure of soluble salts)*	<1.75 mS/cm	<1.0 mS/cm	<1.0 mS/cm
Calcium Carbonates (CaCO3)	<150 ppm	<120 ppm	<120 ppm
Bicarbonates (HCO3)	<150-200 ppm (lower if not leached with rainfall)	<100-150 ppm (lower if not leached with rainfall)	<100-150 ppm
Sodium (Na)	<70 ppm	<60 ppm	<60 ppm
Chloride (Cl)	<140 ppm	<100 ppm	<100 ppm
Sulphur (S)	<70 ppm	<70 ppm	<70 ppm
Sulphates (SO4)	<200 ppm	<200 ppm	<200 ppm
Iron (Fe)	<0.5 ppm	<0.5 ppm)	<05. ppm
Boron (B)	<0.8 ppm	<0.5 ppm	<0.5 ppm

These are guidelines only. Crops will vary greatly in their sensitivity to soluble salts and water chemical properties.

Adapted from: West, J, Huber, A, Carlow C, Water Treatment Guide for Greenhouses & Nurseries, April 9, 2018

Appendix 4

Comparing Yields and Market Values of Leading California Crops

	Production (1,000 tons)	Total Wholesale Value ($1,000)
Cannabis - CA Production (Instate + Exports)*	9.6	$24,765,680
Cannabis - CA Production- For Instate Demand Only**	2.6	$6,799,067
Grapes, All	7,130.0	$6,254,211
Almond (Shelled)	2,280.0	$5,468,040
Pistachios	987.0	$2,615,550
Berries, All Strawberries	1,443.5	$2,340,315
Oranges, All	5,327.0	$1,121,566
Walnuts	676.0	$878,800
Hay, Alfalfa & Other	5,682.0	$769,826
Rice	2,431.8	$755,763
Lemons	966.0	$681,564
Cotton, Lint All	216.5	$548,816
Avocados	171.0	$383,485
Plums and Prunes	190.2	$345,540
Berries, Raspberries	80.1	$331,088
Peaches, All	479.0	$304,213
Potatoes, (Excl. sweet)	772.9	$258,625
Potatoes, Sweet	435.1	$198,912
Cherries, Sweet	44.8	$140,395
Berries, Blueberries	36.3	$139,755
Nectarines	120.5	$104,626
Dates	30.0	$86,109
Grapefruit, All	564.0	$78,872
Cottonseed	339.0	$78,725
Pears, All	161.5	$77,344
Apples	125.0	$71,000
Beans, Dry	59.6	$68,885
Wheat, All	348.2	$68,167
Sugar Beets	1,092.0	$52,761
Grain, Corn	314.9	$52,570
Olives	53.6	$40,523
Apricots	31.7	$38,055
Oil Crops*	121.5	$37,797
Kiwifruit	37.8	$32,886
Barley	43.1	$8,578
Pecans	3.7	$7,400
Oats	6.7	$1,448

** Yield in smokable flower only. Does not include mass of leaf, trip, or bud for extraction. 2019 values. Assumes wholesale market half the value of the retail market (based on prevailing mark-up rates).*

*** Model assumes that California produces approximately 57% of all cannabis consumed in the U.S., with most products sold outside of the state. The state's share of national production will continue to fall as more states legalize.*

Source: California Agricultural Statistics Review 2018 -2019, California Department of Food & Agriculture

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For more information contact:

Sales@NewFrontierData.com

NEW FRONTIER DATA

HEADQUARTERS
1400 I Street NW / Suite 350 / Washington, DC 20005

SALES & MARKETING
535 16th Street / Suite 620 / Denver, CO 80202

LONDON
Smith Building / 179 Great Portland Street / London W1W 5PL

info@NewFrontierData.com 844-420-D8TA

@NewFrontierData

NewFrontierData.com

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